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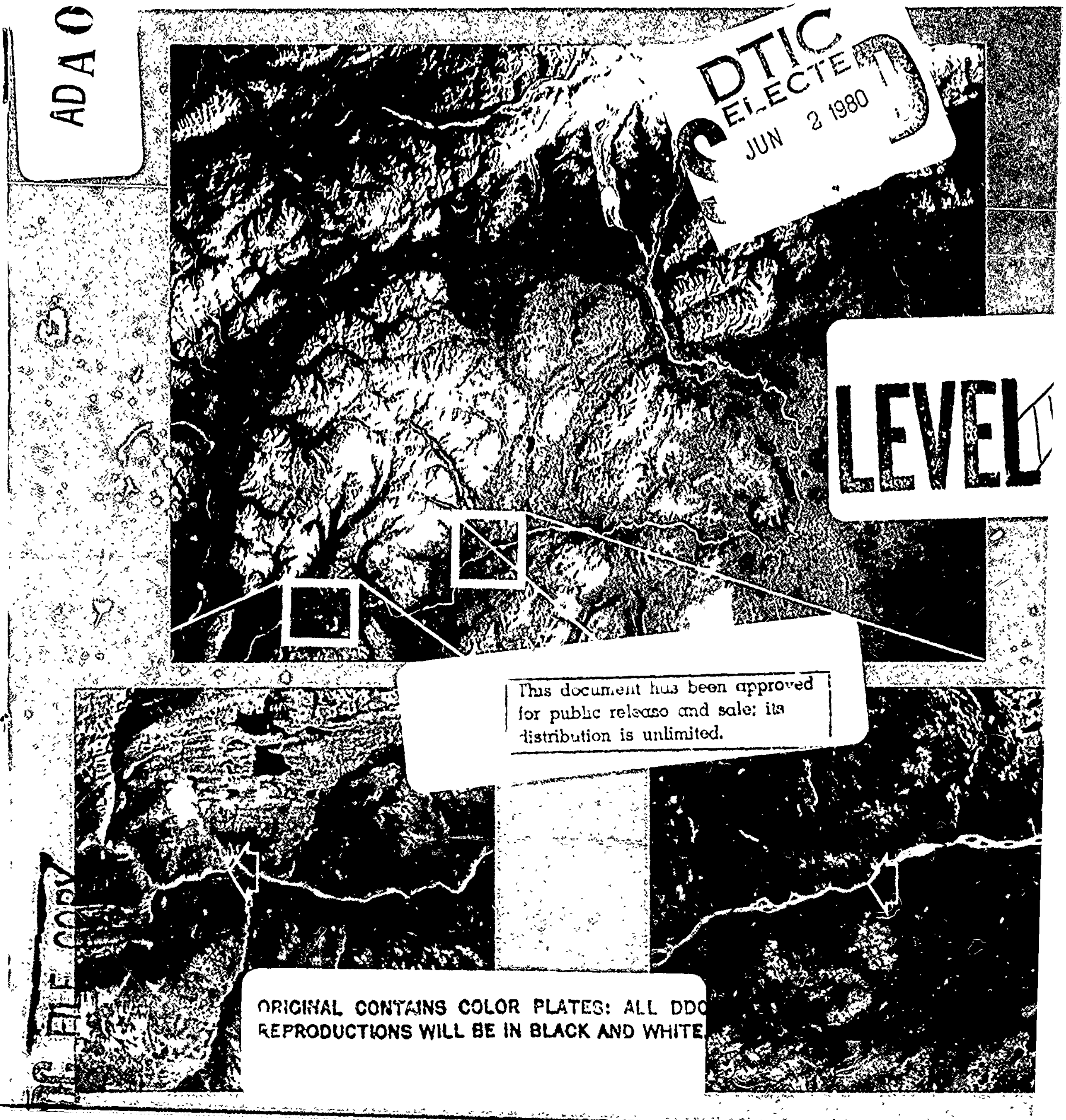
REPORT 80-4

Environmental analysis of the Upper Susitna River Basin using Landsat imagery



For conversion of SI metric units to U.S./British customary units of measurement consult ASTM Standard E380, Metric Practice Guide, published by the American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103.

Cover: Devil Canyon (left) and Watana dam sites along the Susitna River. (The Watana site is approximately 49 km upstream from Devil Canyon.) The Landsat band 5 image (I.D. 5470-19560) at the top was taken on 1 August 1976 from an altitude of approximately 920 km and is at a scale of 1:1,000,000. The bottom photographs are black and white copies of color infrared photography taken by NASA on 28 July 1977 during mission 364 from a 18,200-m altitude. The scale of the photographs is 1:160,000.

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Environmental analysis of the Upper Susitna River Basin using Landsat imagery

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The primary objectives of this study were to 1) prepare a map from Landsat imagery of the Upper Susitna River Basin drainage network, lakes, glaciers and snowfields, 2) identify possible faults and lineaments within the upper basin and within a 100-km radius of the proposed Devil Canyon and Watana dam sites as observed on Landsat imagery, and 3) prepare a Landsat-derived map showing the distribution of surficial geologic materials and poorly drained areas. The EROS Digital Image Enhancement System (EDIES) provided computer-enhanced images of Landsat-1 scene 5470-19560. The EDIES false color composite of this scene was used as the base for mapping drainage network, lakes, glaciers and snowfields, six surficial geologic materials units and poorly drained areas. We used some single-band and other color composites of Landsat images during interpretation. All the above maps were prepared by

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photointerpretation of Landsat images without using computer analysis, aerial photographs, field data, or published reports. These other data sources were used only after the mapping was completed to compare and verify the information interpreted and delineations mapped from the Landsat images. Four Landsat-1 MSS band 7 winter scenes were used in the photomosaic prepared for the lineament mapping. We mapped only those lineaments related to reported regional tectonics, although there were many more lineaments evident on the Landsat photomosaic. Landsat imagery provided useful information on the major drainage patterns, distribution and reflectivity of lakes, geologic features at the terminus of large glaciers, medial and lateral glacial moraines and geologic lineaments. Interpretation of the Landsat imagery for mapping surficial geologic materials without previous knowledge of the past and present sedimentary environments of the study area is difficult and the use of the results may be limited. Satellite and aircraft imagery are more accurately interpreted when the interpreter is familiar with the types of environments present. Landsat imagery provided geologic information in a remote area quickly and cost-effectively. It also provided preliminary planning information and indicated regional differences. It will not, however, supply the detailed site-specific data required for design. Ground truth data are required for all remote sensing investigations using satellite or aircraft data

PREFACE

This report was prepared by Lawrence W. Gatto, Geologist, Carolyn J. Merry, Geologist, Dr. Harlan L. McKim, Soil Scientist, and Dr. Daniel E. Lawson, Research Physical Scientist, of the Earth Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory. The Directorate of Civil Works, Office, Chief of Engineers, funded the majority of the project under Reimbursable Order No. CWM-R-77-3, *Environmental Analysis of the Upper Susitna River Watershed,* supplemented with additional funds under Reimbursable Order No CWE-B-78-10, *Susitna Landsat Analysis Project.* The Civil Works Environmental Impact Work Units, CWIS 31013, *Environmental Effects and Criteria for Engineering Works in Cold Regions,* and CWIS 31568, *Erosion Potential of Inland Shoreline and Embankments in Cold Regions,* provided additional office and field support.

The authors express their appreciation to Eric Yould (formerly of the Alaska District), Glen Greely of the Alaska District, and Gary Flightner, U.S. Army Engineer Division, North Pacific, for assistance in formulating the project objectives, to Dr. Jerry Brown, and Richard Haugen of CRREL, Vern Thompson, Alaska District, and Glen Greeley for technical reviews of this report; to Eleanor Huke for assistance in preparation of the maps and figures; and to Dr. Brown and Thomas Marlar, CRREL, for technical suggestions and comments during the project.

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SUMMARY

Objectives

The overall objective of this investigation was to evaluate the utility of environmental data derived from the interpretation of Landsat imagery for preconstruction planning and design of the hydroelectric project proposed for the Upper Susitna River Basin.

Specific objectives were to:

1. Prepare a map from Landsat imagery showing the upper basin drainage network, lakes, glaciers and snowfields (Part I).

2. Identify possible faults and lineaments as observed on Landsat imagery within the upper basin and within a 100-km radius of the proposed Devil Canyon and Watana dam sites (Part II).

3. Prepare a Landsat-derived map showing the distribution of surficial geologic materials and poorly drained areas (Part IIIA).

5. Evaluate the accuracy of the Landsat-derived surficial geologic materials map by field investigations at selected sites in the basin (Part IIIB).

5. Cooperate and coordinate with personnel from the Alaska District in evaluating these data products and those developed during the Bureau of Land Management (BLM)-National Aeronautics and Space Administration (NASA) Applications System Verification and Transfer (ASVT) Project.

This hydrologic and geologic information should be important in preliminary route and site selection, in bedrock and soils analysis, and in locating construction materials, e.g glacial till, sand and gravel, and quarry rocks.

Conclusions

Landsat imagery provided useful information for the Upper Susitna River Basin. The major drainage patterns and the distribution of lakes in the basin were clearly shown on Landsat imagery. Many small lakes not shown on available 1:250,000 topographic maps were evident on the 1.250,000 Landsat imagery. The imagery also showed differences in the reflectivity of the lakes. The shorelines of some of the small lakes, however, were not well-defined on the imagery.

Many geologic features at the terminus of the large glaciers in the upper basin are well-defined on Landsat imagery The medial and lateral moraines of the glaciers are also apparent. Changes in these features could be documented and analyzed using repetitive coverage of Landsat imagery

Landsat imagery would be a useful tool for updating large-scale maps of river channel configuration and location, midchannel bars and islands, location and features of the glacier termini, and for monitoring changes in river and lake sediment concentrations.

A predominant northeast-southwest set of lineaments and a secondary north northwest-south southeast set appear on the Landsat imagery in a 100-km radius of the

Devil Canyon and Watana dam sites. The predominant lineaments are associated with: 1) the Denali fault zone, 2) the Cretaceous to Recent fault zone, and, 3) the Talkeetna thrust.

The surficial geologic materials map shows the distribution of six general materials units:

b	in-situ bedrock and very coarse, rubbly bedrock colluvium.
bc	coarse- to fine-grained deposits occurring on moderate to steep slopes.
ag	undifferentiated alluvial-glaciofluvial deposits.
fl_1	undifferentiated fluvial-lacustrine deposits.
fl_2	fl_1 deposits, except with fewer lakes and not as poorly drained.
um	unvegetated moraines.

The *b*, *bc*, fl_1, fl_2, and *um* units were easily differentiated; the *ag* unit was difficult because it had many tones and textures on the imagery. Surficial geologic materials mapping took less than 80 hours.

The field investigations for the Landsat-derived surficial geologic materials map indicate that most large areas of exposed bedrock were clearly distinguishable from unconsolidated deposits. As expected, scattered unconsolidated deposits surrounded by bedrock were not recognized by Landsat interpretation. Areas of unconsolidated deposits in which small bedrock outcrops are common were not distinguished from areas without such outcrops.

The types and origins of unconsolidated materials deposited in the glacial and periglacial environment could not be clearly defined with the Landsat imagery. This was particularly true for areas of till and other sediment of similar texture and sorting which were mapped mainly as water-laid sediments

Interpretation of the Landsat imagery for mapping surficial geologic materials without previous knowledge of the past and present sedimentary environments of the study area is difficult and the use of the results may be limited Satellite and aircraft imagery are more accurately interpreted when the interpreter is familiar with the types of environments present Ground truth is always required for detailed studies no matter what type of photo base is used in the interpretation. Without ground truth, the accuracy of a surficial geology map cannot be determined, and therefore care must be taken when using information derived from Landsat imagery alone The information can be useful when regional geologic information is limited or unavailable

Landsat imagery provided geologic information in a remote area quickly and cost effectively. It also provided preliminary planning information and indicated regional differences It will not supply the detailed site-specific data required for design Field data are required for all remote sensing investigations using satellite or aircraft data.

ENVIRONMENTAL ANALYSIS OF THE UPPER SUSITNA RIVER BASIN USING LANDSAT IMAGERY

L.W. Gatto, C.J. Merry, H.L. McKim and D.E. Lawson

INTRODUCTION

Background

Plans are currently being considered for development of the hydroelectric potential of the Upper Susitna River (Fig. 1). These include the construction of two dams and related facilities, i e powerplants, electric transmission works to regional load centers, access roads, and permanent operating and recreational facilities (U.S Army Corps of Engineers 1978a)

The environmental impact statement (EIS) for the Upper Susitna River region is a comprehensive assessment of the proposed project and states the potential adverse environmental effects. As stated in the EIS (U.S Army Corps of Engineers 1975), however, "the current study is in the feasibility stage, impacts are not exhaustively evaluated If the project is authorized and funded for detailed studies, environmental, social, economic and engineering aspects of the project will be studied at length prior to a recommendation to Congress for advancement to final project design and construction."

The following environmental topics were felt to warrant more detailed investigation. soil and permafrost characterizations, structural and surficial geology, potential influence of river flow regulation on floodplain vegetation, ice formation and jams, land use, water quality and snow hydrology This project was initiated to illustrate the use of Landsat imagery in analyzing some of these topics

Previous cooperative investigations

Bilello (1975) reported an analysis of the regional winter environment in the basin. Data were collected and analyzed on the winter climate and on the snow and ice cover from National Weather Service records. The objectives of this study were to 1) combine available information on winter surface conditions, 2) assemble maximum coverage of recent weather data, 3) group weather records for all stations for a concurrent period so that comparisons of the data between stations would be possible, 4) compile information on snowfall amounts and snow depths, densities, and water equivalents, 5) gather data on ice formation, growth and decay on the rivers and lakes, and 6) review and present the data in a form suitable for quick use and easy reference

During 1974, 1975 and 1976, CRREL and the Alaska District collaborated in evaluating the utility of the Landsat Data Collection System in the acquisition and transmission of hydrometeorological data from the proposed Devil Canyon dam site in the Upper Susitna River Basin (Haugen et al 1979) CRREL and District personnel installed a Landsat Data Collection Platform (DCP) at the site in October 1974. The DCP was interfaced with the following sensors: two thermistors (one to measure ground temperature, the other, air temperature), an anemometer, and a snow pillow to measure the water equivalent of the snowpack

The DCP was installed to determine its operational capabilities in a remote cold regions site

and to supplement existing data acquired from the hydrometeorological station network within the basin (Fig. 1). Haugen et al. (1979) reported the results of this evaluation.

Project rationale and coordination

Coordination with the Alaska District for the Landsat investigation began in November 1975 when we were initially formulating the objectives and approach. The actual investigations began in April 1977 when funds were received from the Office, Chief of Engineers.

It was initially agreed between CRREL and the Alaska District that the project would be accomplished using only Landsat imagery interpretation without ground truth to verify the mapped feature. Towards the end of the project we decided to obtain ground truth to assess the accuracy of the surficial geology mapping units. This was accomplished with additional funds during the summer of 1978

Initial coordination meetings with personnel from the District, BLM, NASA, University of Alaska (UA), EROS Data Center (EDC), U.S. Fish and Wildlife Service (FWS), and U.S Soil Conservation Service (SCS) were held from 27 April to 5 May 1977 This project required close coordination between representatives from the District, CRREL, and the other agencies involved in the Applications System Verification and Transfer (ASVT) project Additional meetings and discussions with all parties occurred periodically throughout the investigation

The ASVT project evaluated in detail the types and accuracy of information on geology, geomorphology and vegetation that are obtainable from Landsat imagery and multiscale aerial photographs (Waller 1977, Dean 1979). The ASVT project site was restricted to the northern portion of the upper Susitna River Basin, and the area west and east of the basin along the Denali Highway

APPROACH

Landsat imagery*

Satellite orbital characteristics

Landsat-2 and -3 are currently operating in 920-km near-polar earth orbits** Each satellite completes 14 orbits per day, three over Alaska. Each orbit takes about 103 minutes. The orbits over Alaska on each day are adjacent and west of the previous day's orbits.

Because the Landsat near-polar orbits converge toward the poles, there is approximately 60% sidelap on the imagery taken on successive days at the high latitudes of Alaska. This sidelap allows the same point in Alaska to be covered by each Landsat on three successive days. The orbits also permit repetitive coverage of any area in the world at the same local time every 18 days

Multispectral scanner

Each satellite carries two imaging systems, a multispectral scanner (MSS) and a return beam vidicon (RBV). We used only the MSS imagery for this investigation.

The MSS is a line scanning device that provides images of an area approximately 185 km square. Each image consists of many individual picture elements (pixels) that are obtained in rapid succession by means of an oscillating mirror behind the lens of the MSS (NASA 1972). The oscillating mirror scans a 185-km-long swath perpendicular to the spacecraft path. The MSS simultaneously records in four spectral bands the amount of light being reflected from a 58- × 70-m area of the earth's surface, the size of one pixel The four spectral bands are: band 4, 0.5-0.6 μm (blue-green), band 5, 0.6-0.7 μm (yellow-red), band 6, 0.7-0.8 μm (near infrared), and band 7, 0.8-1.1 μm (near infrared).

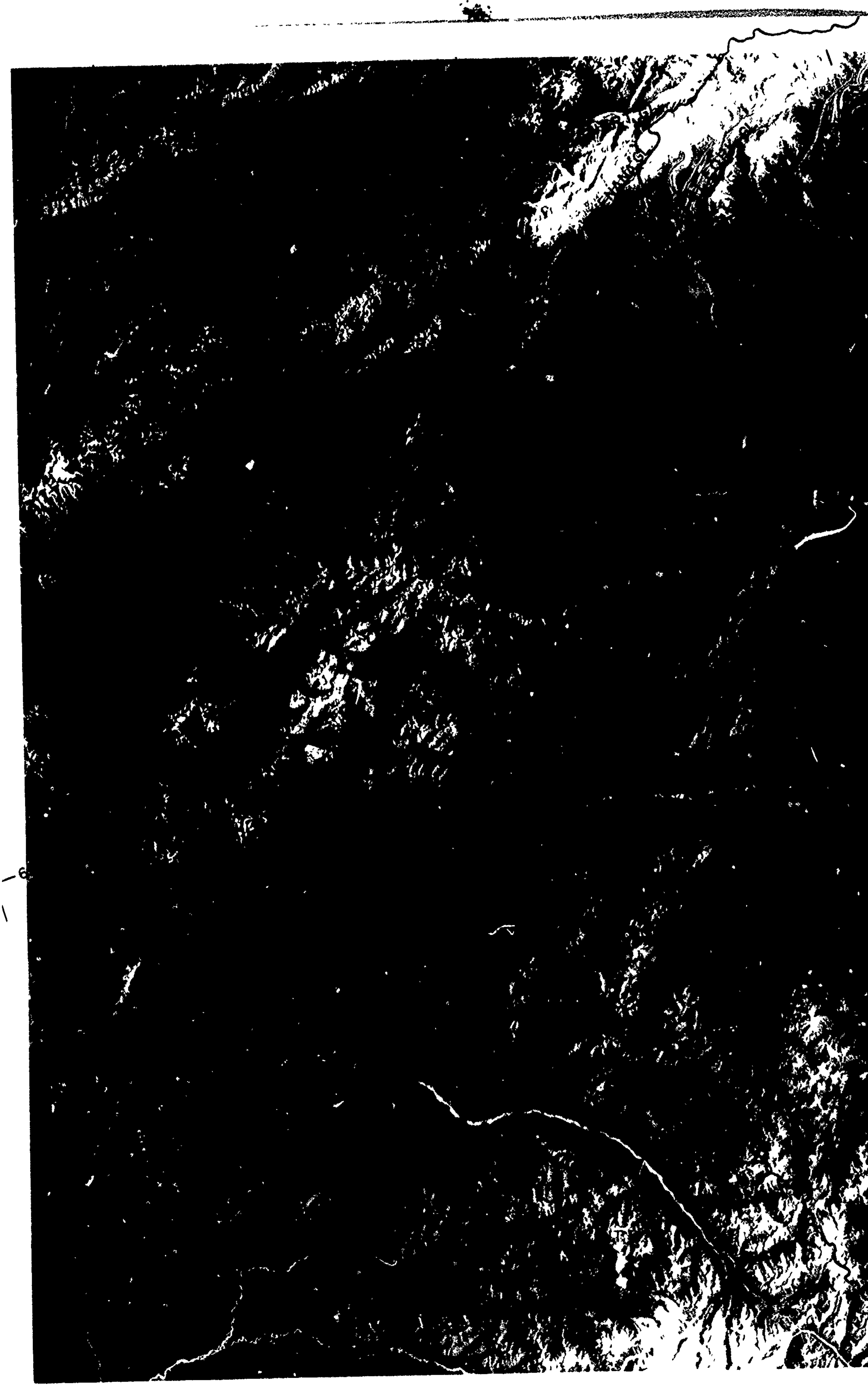
The MSS video signal is converted to digital data and telemetered to a receiving station on earth, either in real time or after being recorded onboard. The final data products include computer compatible tapes (CCTs), black and white photographs of individual spectral bands (bands 4-7), and color composites comprising several bands, usually bands 4, 5 and 7 or bands 4, 5 and 6

Gray tones

A 15-step gray scale appears on every Landsat image The gray scale shows the relationship between a level of gray on the image and the electron beam density used to expose the original image. The electron beam density is related to the energy incident on the MSS detectors. This incident energy is related to that reflected from features on the Earth's surface The variations in incident energy produce the tones, textures, and

*Based on Anderson et al (1973)

**Landsat 1 operations were terminated on 6 January 1978



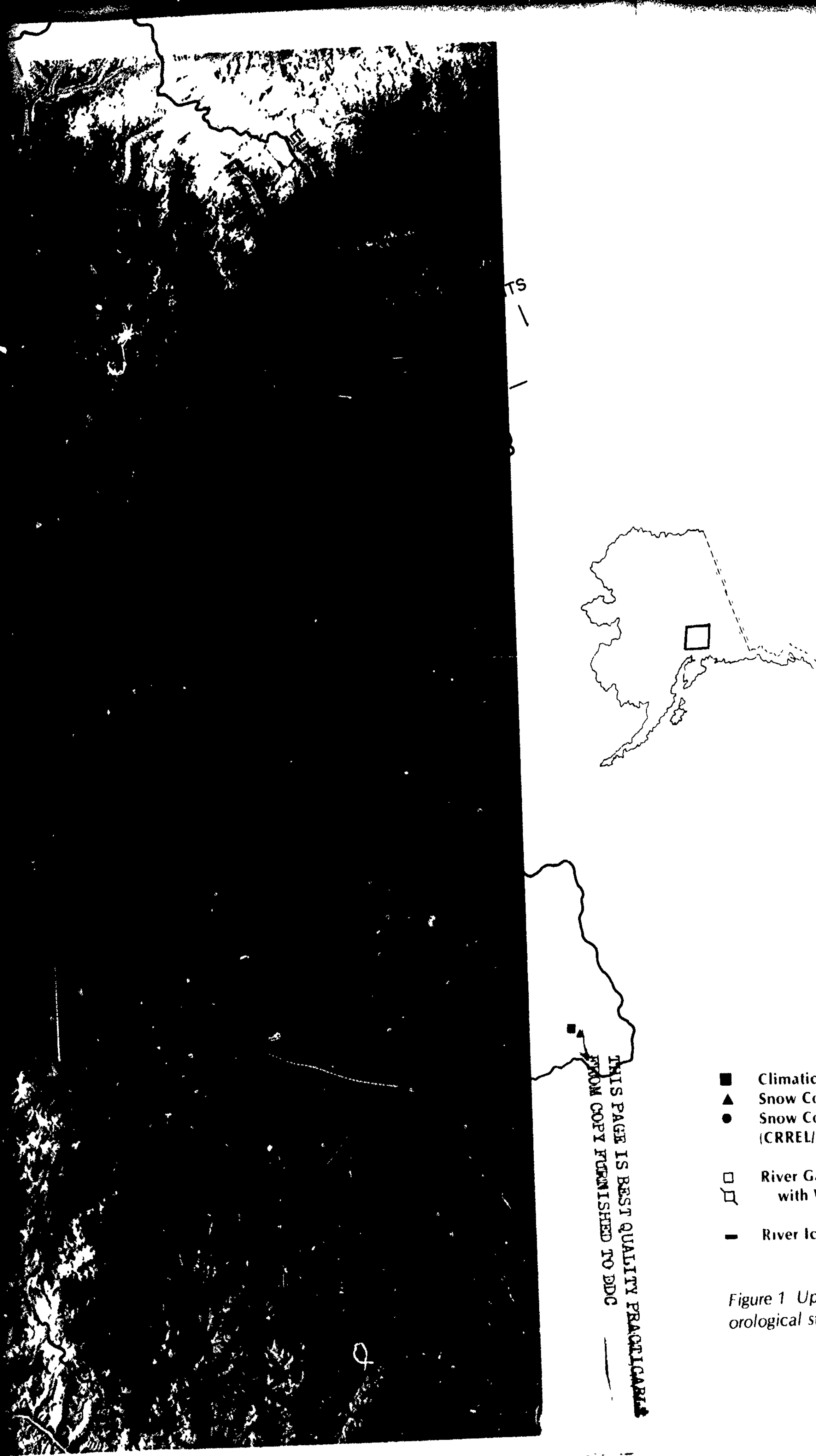


Figure 1 Upper Susitna River Basin and hydrometeorological stations within and near the Basin

patterns on the Landsat imagery that we used during photointerpretation.

Resolution and positioning

The smallest circular, oblate or rectangular object detectable by the MSS can be no smaller than 58 × 70 m. It is, however, possible to identify smaller linear features such as streams, transmission line right-of-ways, drainageways and road networks when the contrast between them and the surrounding terrain is great.

The approximate geographical location of features relative to one another may be determined directly from the Landsat imagery. An accurate positioning of features is also possible when the imagery is used in conjunction with USGS 7.5- or 15-minute topographic maps.

Sun elevation effects

Changes in the local sun elevation angle cause variations in the illumination of a particular area. When the sun angle is low, solar illumination tends to enhance topography, and geomorphic detail of topographic features is more obvious. Features with small topographic relief are generally obscured when sun elevation angles are low.

Cloud cover

A major limitation in the use of Landsat imagery for environmental studies in Alaska is cloud cover. Cloud cover statistics from 20 stations in Alaska averaged over a seven-year period showed that most locations averaged more than 70% cloud cover throughout the year (Table 1) Although the cloud cover may not always be opaque to the MSS, a thin cloud layer partially obscures surface features and detail, and interpretation becomes more difficult

Table 1. Cloud cover, seven-year mean value from 20 stations in Alaska (Anderson et al., 1973, p. 4).

January	6.7*	May	7.7	September	8.0
February	7.2	June	8.0	October	7.9
March	7.0	July	8.4	November	7.7
April	7.2	August	8.3	December	7.4

*Scale 0 (clear) to 10 (complete cloud cover)

Snow cover

A snow cover enhances certain topographic features not readily apparent without it. Snow enhances forest boundaries but obscures low vegetation. Many subtle relief features such as glacial moraine topography, thaw lake morphology and riverine features are better defined on images with snow cover than on snow-free images of the same area. Wobber and Martin (1973) report that a heavy blanket of snow (> 22 cm) accentuates major structural features, whereas a light dusting (< 2 cm) accentuates more subtle topographic expressions.

Interpretation techniques

We decided to use manual photointerpretation techniques rather than automated interpretation for two reasons First, the manual techniques require less sophisticated equipment The imagery can be easily obtained and used Consequently, scientists and engineers in the Corps' Districts would be more likely to use photointerpretation themselves before becoming involved in more advanced, automated computer analysis techniques. Secondly, the BLM-NASA ASVT project included extensive use of computer techniques for analysis of Landsat imagery There was no need to duplicate their evaluation and demonstration of computer techniques

The same photointerpretation technique was used for all parts of this investigation. The Alaska District and CRREL agreed that the drainage network, lakes, glaciers and snowfields, lineaments, and surficial geologic materials were to be mapped solely on the basis of tones, textures and patterns visible on the Landsat imagery In some cases image sidelap permitted stereo viewing. We later compared our maps and observations made strictly from Landsat interpretations to published maps and reports, aerial photographs, and ground survey data

Usually geologists make limited ground surveys prior to geologic mapping to become familiar with site-specific geology, and then use satellite and aerial imagery to prepare regional maps This field-to-regional approach was intentionally not followed in this study so that the Landsat imagery alone could be interpreted and evaluated

The aerial photographs later used for comparison with the Landsat interpretations were taken on 24, 28, and 29 July 1977 (NASA Mission

364, Project 565) with two Zeiss metric cameras with lenses of 15-cm and 30-cm focal length from a NASA WB-57 aircraft along 14 flight lines at altitudes of 9100 m and 18,200 m. Film was Aerochrome Infrared (2443). The photography was obtained by NASA in support of the BLM-NASA ASVT project.

The feature identifications and mapping discussed in Parts I and IIIA of this report were done from the 1:250,000 scale EDIES* color composite photograph (Fig. 2 and 3) used for the mapping base, the EDIES single band images of the same scene and other standard Landsat images at various scales

Possible faults and lineaments (Part II) were mapped on a photomosaic (Fig. 2) made with 1:250,000 scale enlargements of standard Landsat images obtained in the winter of 1972

During the field observations in 1978, the NASA aerial photographs and the EDIES color composite were used to check for characteristic tones and textures of unconsolidated sediments (Part IIIB).

Some of the standard Landsat images were photographically enhanced and enlarged from 70-mm and 184-mm positive transparencies. High contrast printing techniques were also used to enhance the contrast and the topographic relief in the basin on some of the low contrast Landsat images.

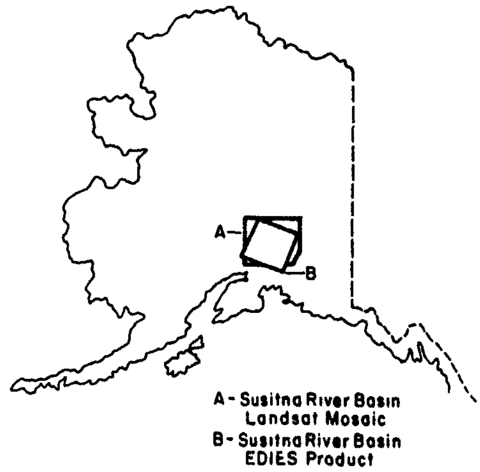


Figure 2. Location of the EDIES product and the photomosaic used for mapping.

*EDIES EROS Digital Image Enhancement System, at the U S Geological Survey EROS Data Center, Sioux Falls, South Dakota

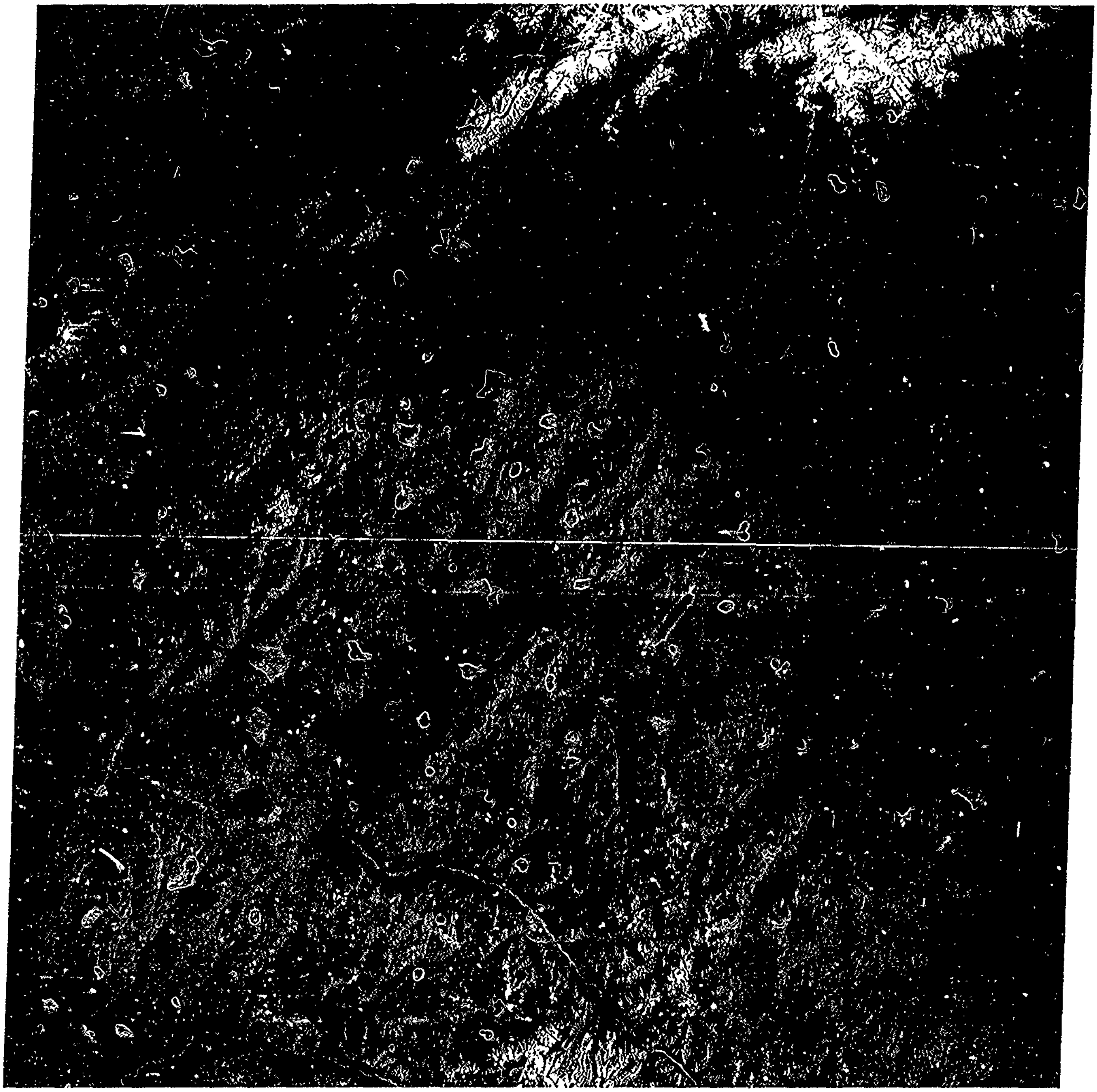


Figure 3. EDIES false color composite of scene 5470-19560 taken 1 August 1976.

PART I. USE OF LANDSAT IMAGERY IN MAPPING THE DRAINAGE NETWORK, LAKES, GLACIERS AND SNOWFIELDS

Lawrence W. Gatto

Objective

The objective of this portion of the study was to map the drainage network and distribution of lakes, glaciers, and snowfields in the upper basin from Landsat imagery. The map was then evaluated by comparing it to available maps and aerial photographs. These types of data are important for analyzing the basin drainage network, and for estimating runoff volumes, timing, and the water retention characteristics of the basin.

Methods

A computer search showed 561 Landsat-1 and 328 Landsat-2 scenes available for the upper basin as of March 1977*. I selected the scene for use as the mapping base contingent on the percentage of the basin shown on the image, amount of cloud cover, time of the year, and date and quality of the image.

Landsat-1 scene 5470-19560 was chosen because it was acquired on 1 August 1976, showed most of the upper basin, was virtually cloud free, showed vegetation during maximum growth, and was of high quality.

I used an EDIES false color composite (Fig. 3) of this scene as the mapping base because the EDIES products are the best computer enhanced photographic products easily obtainable by District personnel. The EROS Data Center prepared the composite from bands 4, 5 and 7 data and enlarged it to an approximate scale of 1:250,000.

Before interpreting the Landsat imagery, I transferred the boundary of the upper basin to the Landsat image mapping base by visually fitting an overlay of the boundary traced from U.S. Geological Survey 1:250,000 topographic maps for Healy, Mt. Hayes, Gulkana, and the Talkeetna Mountains.

*Landsat-3 was launched on 5 March 1978

The overlay did not always fit precisely over the EDIES base due to slight scale variations between the base and the topographic maps. Consequently, in locations where the fit was poor, the boundary was drawn free-hand by comparing contour data on the topographic maps to respective features observed on the Landsat photo base. In the three locations where the boundary goes off the Landsat base, I simply traced the basin shape from the overlay.

During the interpretation, I occasionally referred to the single band EDIES images (Fig. 4a-d) of scene 5470-19560 and the single band and color composite images of Landsat-1 scenes 1103-20511 (3 November 1972), 1408-20441 (4 September 1973), and 1768-20345 and 1768-20351 (30 August 1974). Previous mapping studies (Anderson et al. 1973, Anderson et al. 1975, Gatto 1976, McKim et al. 1975, McKim et al. 1976a, McKim et al. 1976b) had shown that different types of hydrologic, geologic and vegetative information could be obtained from multispectral images as single bands or as composites.

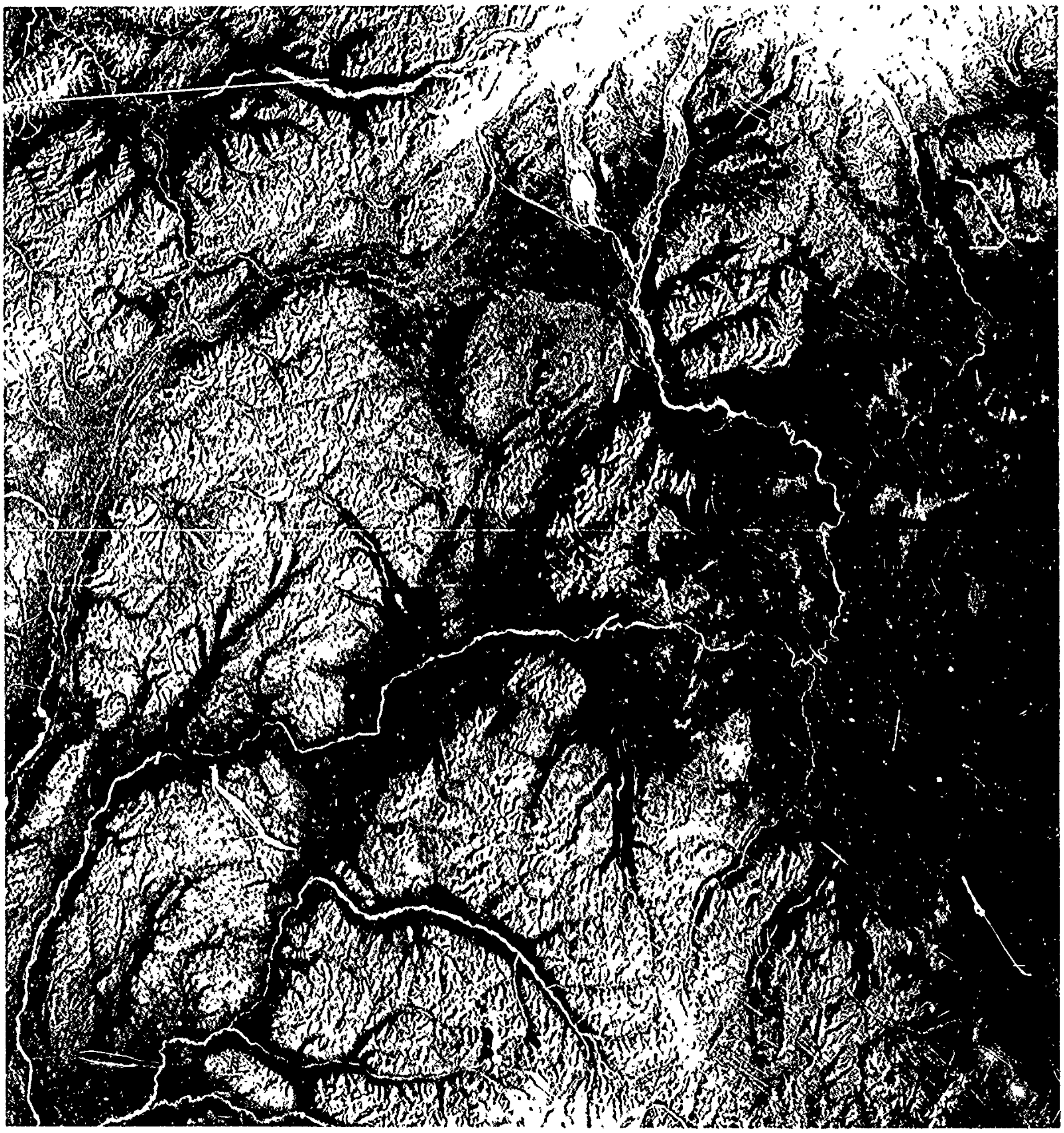
I prepared all maps by photointerpretation of Landsat images without using computer analysis, aerial photographs, field data, or published reports during map preparation. These other data sources were used only after the mapping was completed to compare and verify the information interpreted and delineations mapped from the Landsat scenes.

Results

Observations

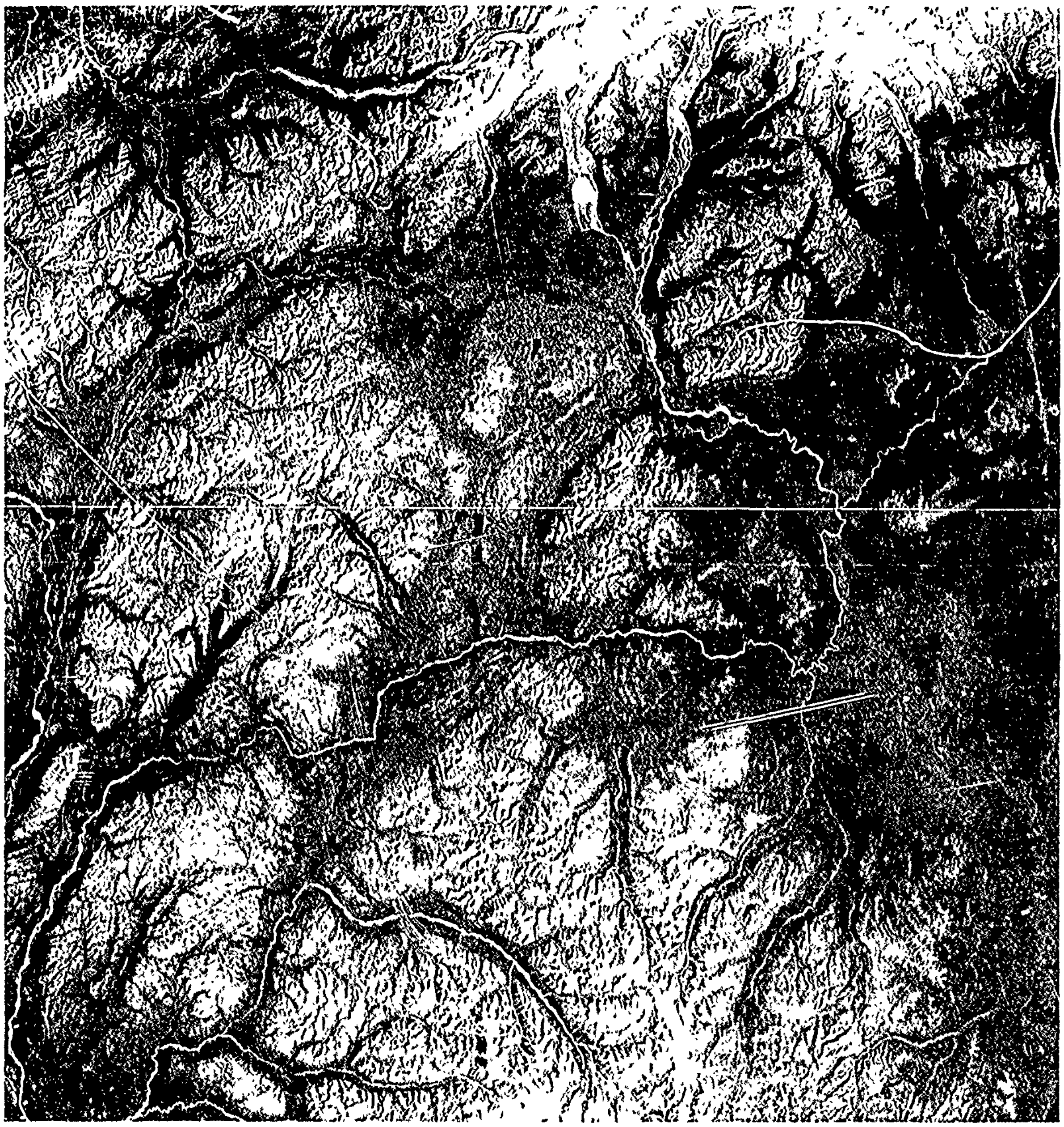
Band 5 images provided information not obtainable from band 7 images and vice-versa. Band 7 always showed the water-filled portion of stream beds, which was not always possible with the band 5. The contrast between land and water on the band 5 image was not always sufficient to differentiate the shoreline. This contrast was usually more apparent on band 7. Consequently, both band 5 and 7 images were used during the mapping.

The tones of the river and lake water on the EDIES color composite (Fig. 3) were variable. These variations may result from differences in



a. Band 4.

Figure 4. Single band EDIES images of scene 5470-19560.

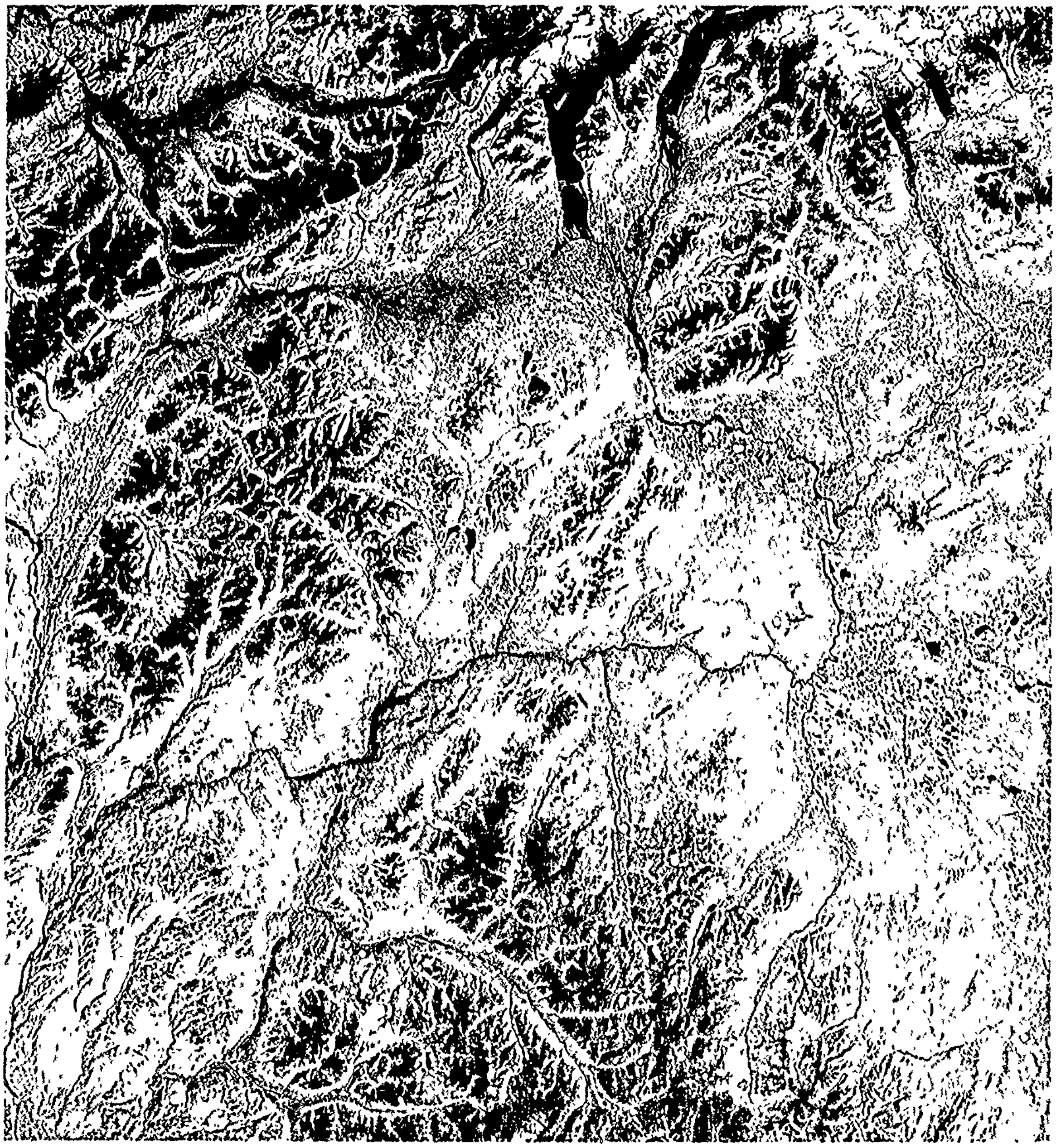


b. Band 5.

Figure 4 (cont'd). Single band EDIES image of scene 5470-19560.

c. *Band* 6.

Figure 4 (cont'd).



d. Band 7.

Figure 4 (cont'd). Single band EDIES image of scene 5470-19560.

suspended sediment and organic material concentrations, or from changes in the amount of light reflected from the bottom of the river or lake.

Deep water with a low suspended material concentration generally appears dark blue or black, whereas deep water with a high concentration of sediment and organics will appear light blue.

Shallow water, which allows a large amount of sunlight reflection from the bottom, appears light blue, although some of the light tone may also result from a high suspended material concentration.

In some cases relative differences in lake water depths can be inferred from the melt pattern of the ice cover (Sellmann et al. 1975). I observed ice in some of the lakes on several of the spring Landsat images. Depending on lake depth and bottom configuration, the ice cover distribution may correspond to the deep portions of lakes where water stays below freezing temperatures longer than in shallower locations.

During a cursory examination of the EDIES mapping base image, I observed highly reflective objects in some of the stream valleys and initially thought that they were river icings However, after further discussions I concluded that these features were more likely stream channel gravel or sand bars. Verification of these features on NASA aerial photographs showed that the reflective objects were channel bars.

Some of the lakes which were apparent on Landsat-1 scenes 1768-20345 and 1768-20351 acquired on 30 August 1974 were not apparent on the EDIES mapping image taken on 1 August 1976. Suspended sediments in the lakes may have differed between 1974 and 1976, causing them to resemble exposed deposits on the 1976 scene

The Landsat imagery clearly shows the distribution of braided channels on the glacial outwash plains, midchannel bars and islands in the Susitna River, and differences in suspended sediment concentrations in the basin rivers. NASA photograph 16-060 (Fig 5) points out the tonal differences (3) between the Maclaren (1) and Susitna (2) rivers that were apparent on the EDIES base (Fig. 3) Also, the bars (1) and islands (2) apparent on the Landsat scene and the NASA photograph 16-040 (Fig 6) are virtually identical in general shape and in location along the channel.

It was also possible to observe the changed locations of some channel bars, and that meltwater stream locations had changed near the termini of several glaciers.

Drainage network

The drainage network pattern of a basin indicates the influence of slope, differences in bedrock, structural control, recent tectonism, and the geologic and geomorphic history of the basin. Therefore, considerable geologic information can be inferred from the drainage network. The drainage pattern can be used in analyzing geomorphic features. This analysis is helpful in understanding structural and lithologic control for land form development (Thornbury 1954).

When mapping the drainage network, I mapped streams and rivers that were visible on the Landsat images or that could be inferred from vegetation patterns (Fig. 7). Frequently, stream or river water was not evident because the streams were intermittent, very shallow, or very narrow. In these cases, I inferred that streams were present when there were well-defined valleys. These valleys usually occur in the mountainous or hilly portions of the basin, are steep-sided, and have little or no floodplain. Stream channels that were difficult to distinguish in areas of low relief were not mapped.

I included the midchannel bars and islands along braided rivers as part of the river (Fig. 7). The small individual channels that compose a braided river were not delineated separately. As a result, downstream from a glacier terminus, the drainage map shows the active floodplain, not just the river channel.

The overall drainage pattern of the upper Susitna River Basin is dendritic (Fig. 7). Usually, the angles of confluence between streams are considerably less than 90°. Except for the two bends of nearly 90° along the Susitna River between the proposed dam sites, most of the major river confluences within the basin are considerably less than 90°.

Typically, a dendritic pattern develops on rocks of uniform resistance where most of the drainage is not structurally controlled (Gilluly et al 1968) Usually, the lack of structural control is found in areas with nearly horizontal sedimentary rocks or massive igneous rocks, or with folded or complexly metamorphosed rocks when the river is superposed (Thornbury 1954)

In the central portion of the basin between Big Lake on the west and the inside of the large loop in the Susitna River, the drainage appears to be

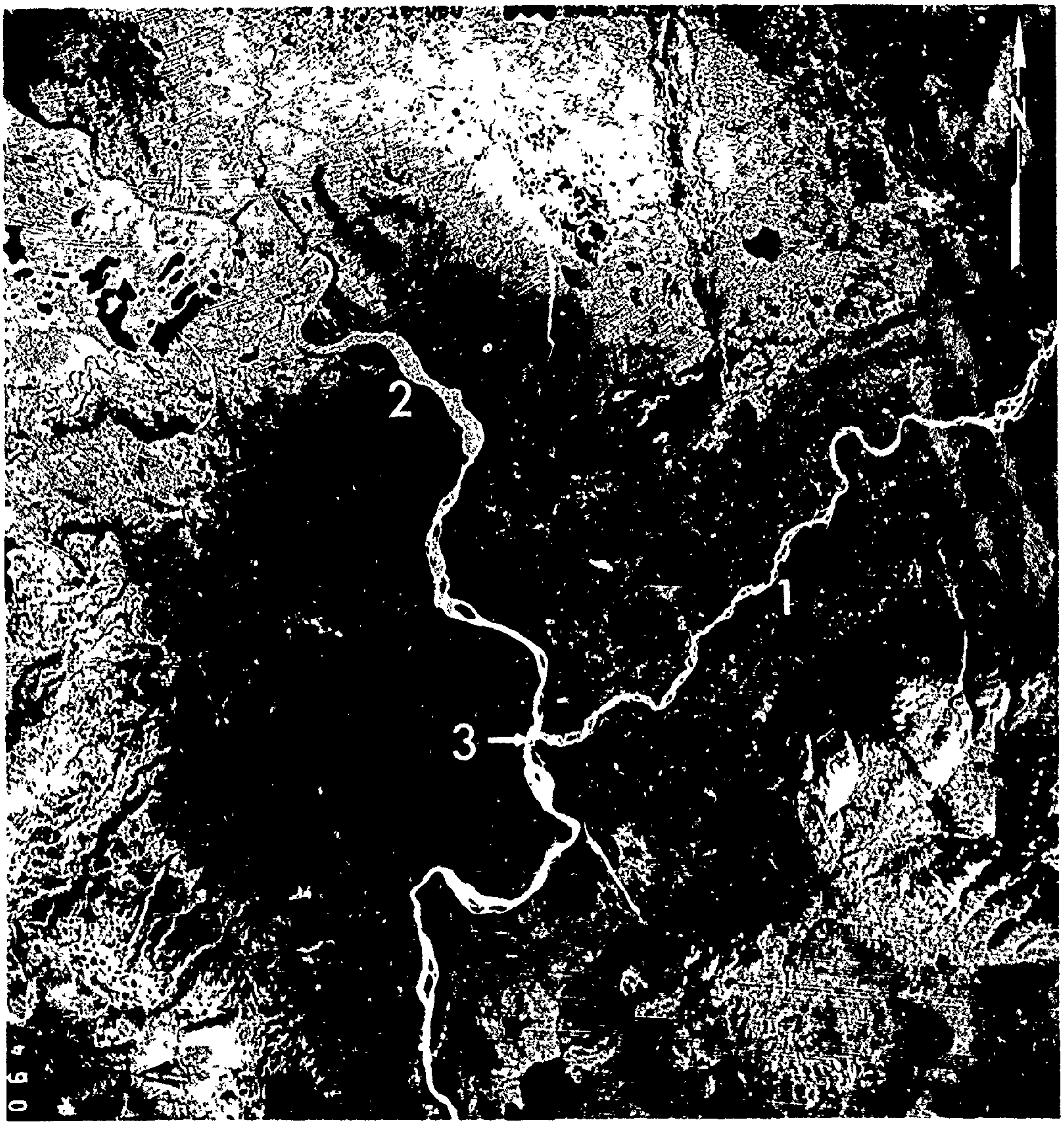


Figure 5. Confluence of the Susitna (2) and Maclaren (1) Rivers, note tonal difference (3), taken on 28 July 1977 during NASA mission 364; scale, 1:160,000

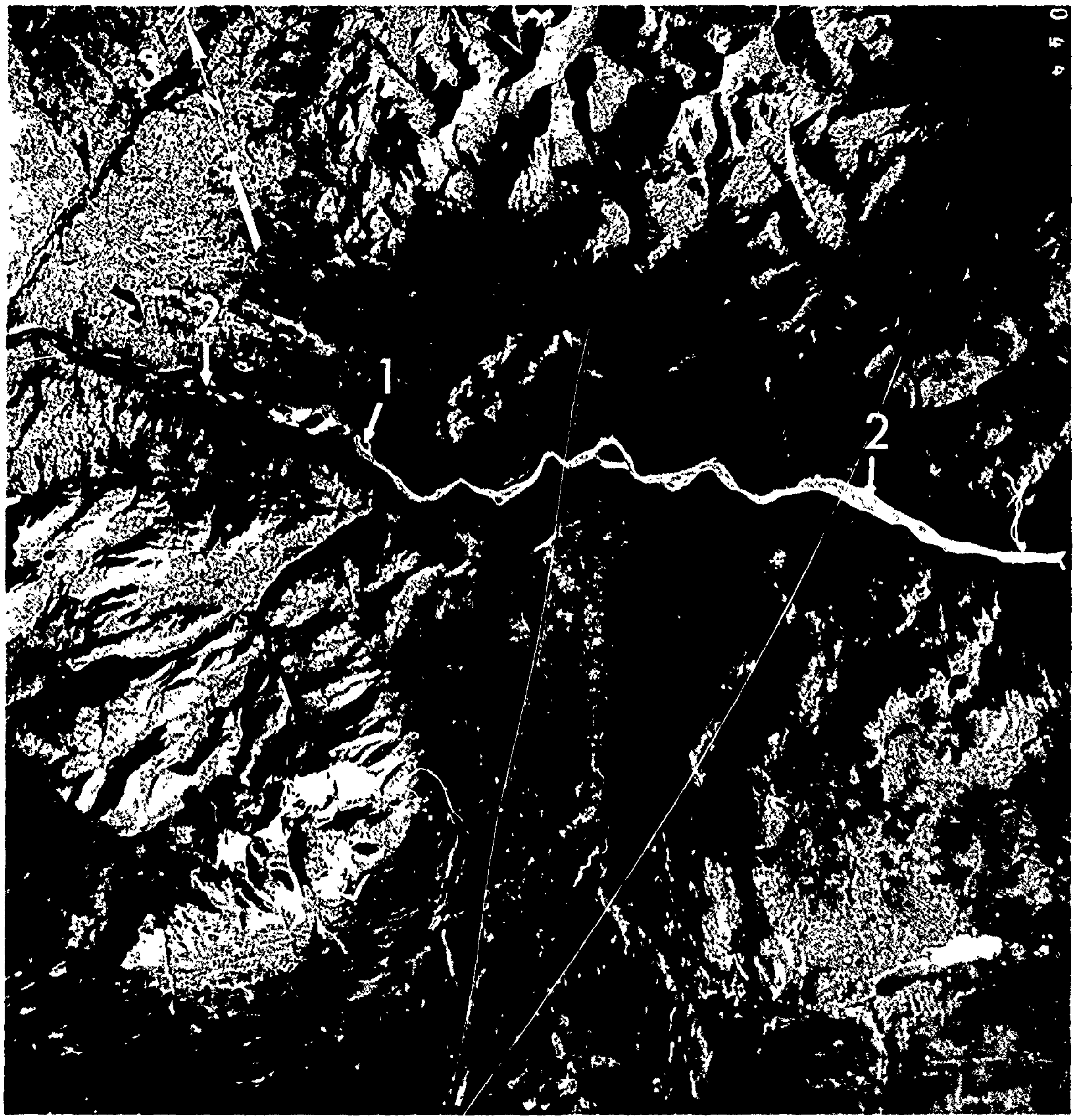


Figure 6. Channel bars (1) and islands (2) in the Susitna River upstream from the Watana Creek (3); taken on 28 July 1977 during NASA mission 364; scale, 1 160,000.

radial. Radial drainage patterns have streams diverging from a central elevated area, i.e. a dome, volcanic cone, or some other isolated conical or subconical hill (Thornbury 1954). The radial appearance in this basin may result from this classic type of topography or it may be a result of the Susitna River bending around these central uplands and receiving runoff from both sides (Dean 1979). This would result in a radial appearance.

Between the source area of the Oshetna River and Susitna Lake, a small portion of the drainage pattern resembles a parallel pattern. Parallel patterns typically occur where slope or structural controls are strong. These controls cause regular spacing of parallel or near-parallel streams (Thornbury 1954).

The presence of three different drainage patterns is not surprising because of the complex geologic history of the basin and its large area, approximately 16,210 km^2.

I compared the Landsat-derived map of the drainage network to the U.S. Geological Survey hydrologic overlays used to prepare the 1:250,000 Healy, Talkeetna Mountains, Mt. Hayes, and Gulkana topographic maps.

The drainage network, lakes, glaciers, morainal areas, channel bars along the streams, and swampy areas on part of the Healy map are shown in Figure 8. Since the aerial photographs used to make the topographic maps were taken from 1947 to 1957, many of the differences in the stream channels, especially those proximate to the glacial terminus, are a result of natural changes that have occurred between 1957 and 1976. These differences are not necessarily due to differences in the resolution of the aerial photographs and the Landsat imagery.

The number of streams shown on the Healy topographic map (Fig. 8) is much greater than I mapped from Landsat imagery (Fig. 7) I was unable to see some of the small tributaries on the imagery because of the Landsat MSS pixel resolution, 58×70 m.

The small streams are frequently narrower than this minimum detectable size The light reflected from the small streams and other features smaller than this area is integrated into one brightness value for the whole area Consequently, small streams, features and objects are frequently not recorded as distinct patterns on the Landsat imagery but appear as part of the surrounding bedrock, sediment, talus, or vegetation

Many of the small streams are shallow. Bottom reflection of solar radiation from the bed of these small streams can be great. The amount of reflected radiation the Landsat MSS receives from the stream water can be small compared to that received from the bottom. As a result, the scanner "sees" the stream in the mountainous areas as similar to the surrounding rocks. In lowland areas, this stream may look like one with high suspended sediment concentrations.

Generally, most of the larger streams in the basin were visible on the imagery. The Healy topographic map and comparable Landsat maps show this. However, the streams north of Big Lake (1, Fig. 8) and southeast of Butte Lake (2) are an exception. There is a major difference between the Landsat map and the Healy map. Inspection of this area in Figure 4d indicates that the drainage network is not very apparent on this Landsat image.

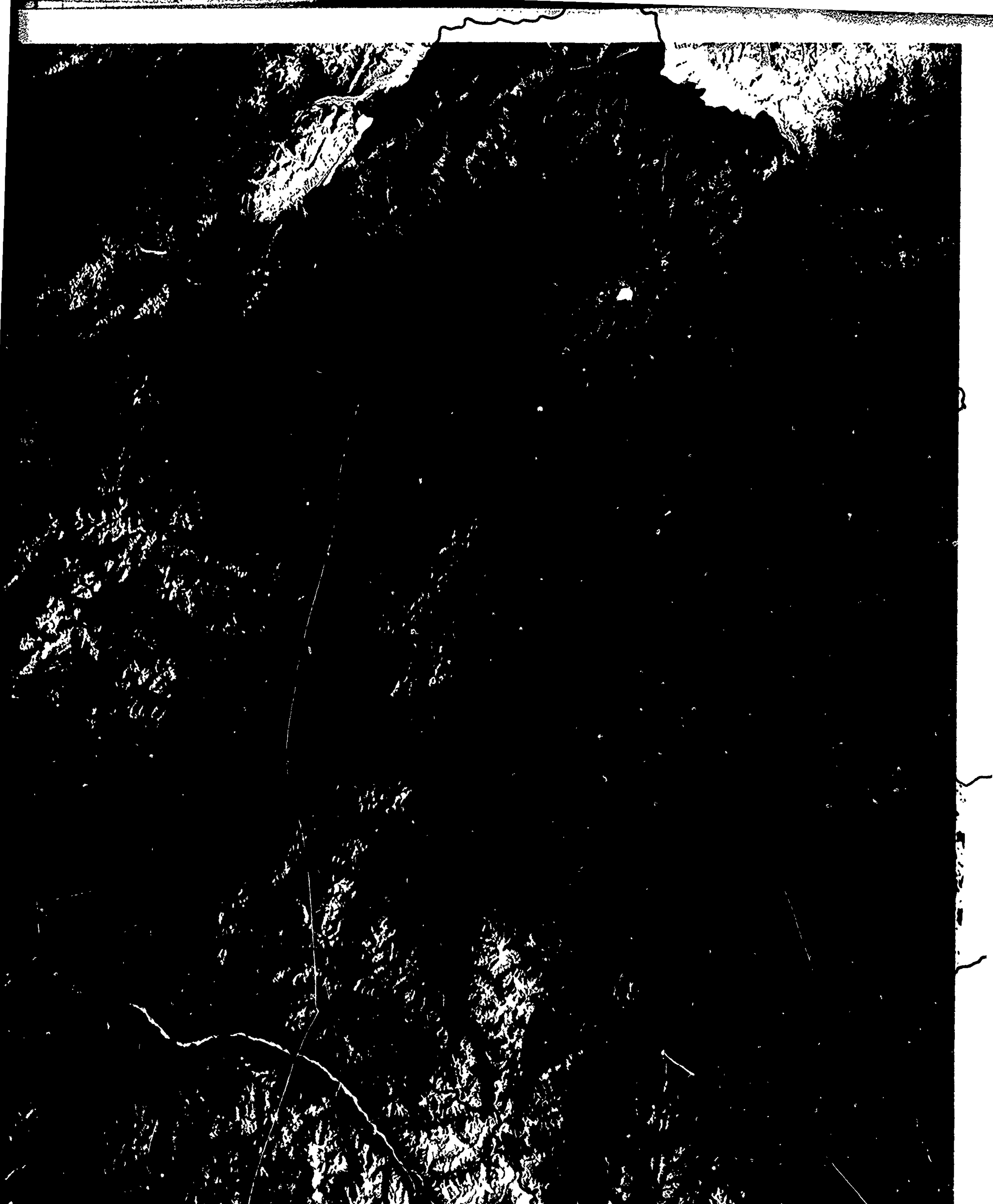
The Landsat imagery was useful in mapping the large-scale drainage network of the basin; it was insufficient for defining the myriad of small-scale drainage features.

Lakes

I compared the distribution of lakes mapped from the Landsat imagery to that on the NASA aerial photographs and the Healy topographic map. NASA photograph 16-054 (Fig. 9) shows the lakes in the Big Lake (1) area of the basin. Most of the lakes shown can also be seen on the Landsat EDIES image (Figs. 3 and 4d). NASA photograph 16-060 (Fig. 5) shows the area around the confluence of the Maclaren and Susitna rivers. Many of the lakes are so small that their shape could not be mapped accurately but are easily observed on the Landsat scene. Frequently, the shape of the lakes is not as well-defined on the Landsat image as on the NASA photographs because of the difference in resolution between the photographs and the imagery.

The lake distribution between the outwash plain (1, Fig 10) of the West Fork Glacier and Butte Lake (2) is apparent on NASA photograph 19-035 and the band 7 Landsat EDIES image (Fig. 4d). The lakes which appear on these photographs are more comparable to each other than to those mapped on the Healy topographic map. There are many more lakes present than shown on the topographic map The NASA photographs and Landsat imagery show present conditions more accurately than the existing map.

The U S. Geological Survey generally does not



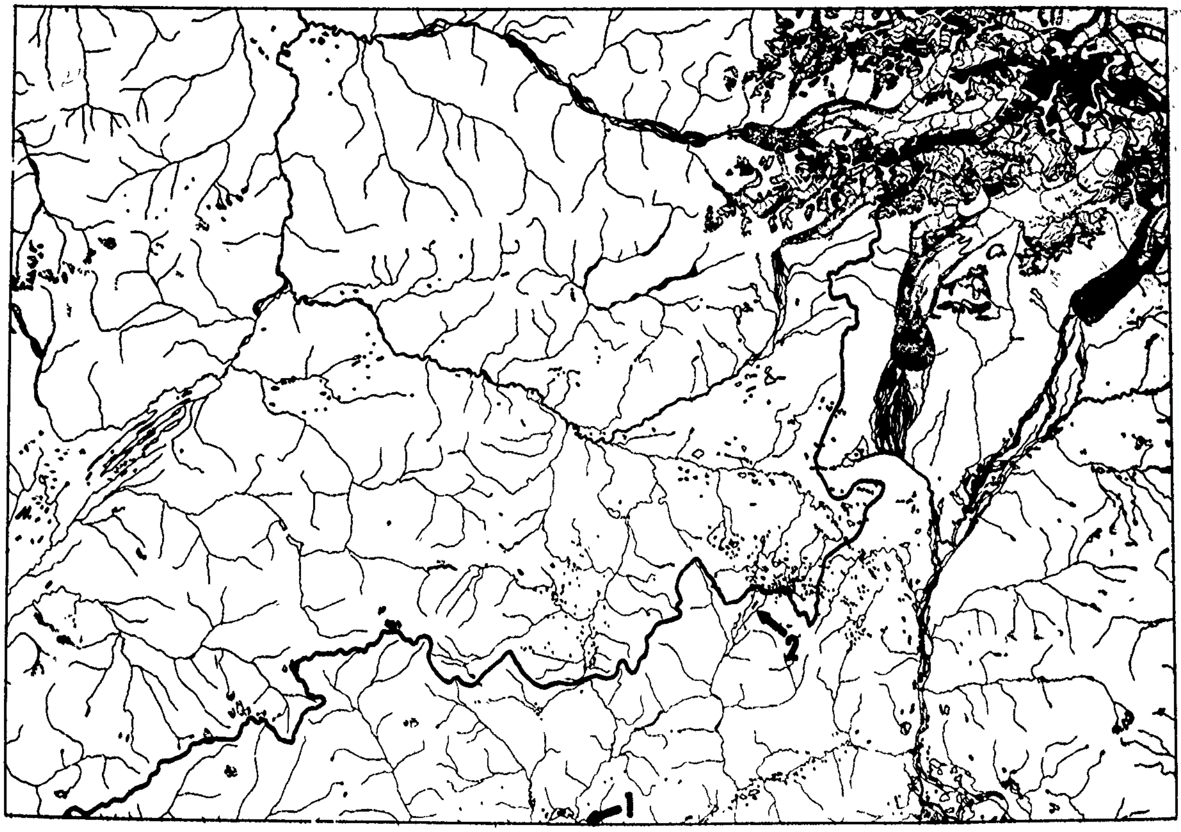


Figure 8. Drainage network, lakes, glaciers, morainal areas, channel bars, and swampy areas on the USGS Healy topographic map, scale 1:250,000; Big Lake (1) and Butte Lake (2).

include lakes smaller than approximately 222 m in diameter on their 1:250,000 topographic maps. Experience has shown that lakes smaller than this cannot be adequately drawn and tinted*.

Landsat imagery, therefore, can be useful in revising maps of lake distribution. This Landsat-derived map would in many cases be more detailed than presently available maps of equivalent scale.

I determined the smallest lake visible on the Landsat imagery by comparing the lakes on the Landsat EDIES color composite and the band 7 EDIES transparency with those on the original NASA color infrared prints. The lake (3) in Figure 11 was only faintly visible on the Landsat EDIES transparency as an indistinct smudge—not as a lake. Consequently, I did not map this lake while preparing the Landsat-derived map of the lake distribution. This lake is also not shown on the USGS 1:250,000 scale Talkeetna Mountains topographic map.

The approximate diameter and surficial area of lake 3 in Figure 11 are 50 m and 2000 m^2, respectively, and the lake is only marginally visible on the Landsat imagery. The approximate diameter and area of lake 4 are 100 m and 8000 m^2, respectively; this lake is clearly visible (Fig. 4d), and was mapped (Fig. 7). Therefore, the smallest lake clearly visible on the EDIES imagery would have a diameter of approximately 100 m and a surficial area of approximately 8000 m^2, roughly equivalent to two Landsat pixels. Each Landsat pixel is 70×58 m or 4060 m^2.

McKim et al. (1972) reported that most water bodies of about 152 m in diameter or approximately 18,000 m^2 in area are apparent on standard, non-enhanced Landsat imagery. They reported that the standard imagery generally does not supply information suitable for observing water bodies of less than 24,000 m^2

*John Zydik, Chief, Map Editing Section U S Geological Survey, Denver, Colorado (personal communication 1979)

Figure 9. Big Lake (1) and surrounding area, taken on 28 July 1977 during NASA mission 364; scale, 1:160,000.

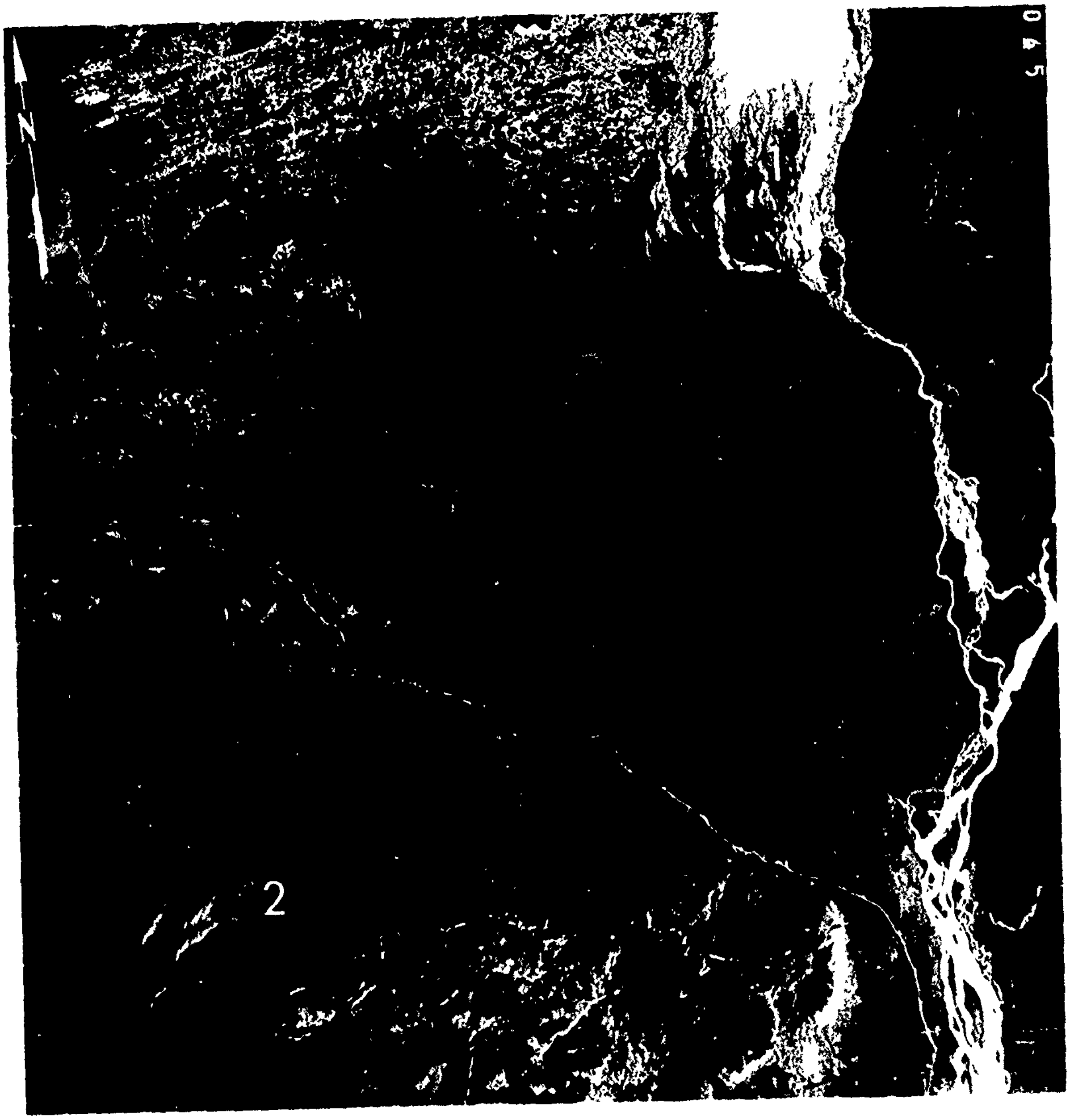


Figure 10. Area between the outwash plain (1) of West Fork Glacier and Butte Lake (2), taken on 29 July 1977 during NASA mission 364; scale 1:160,000.

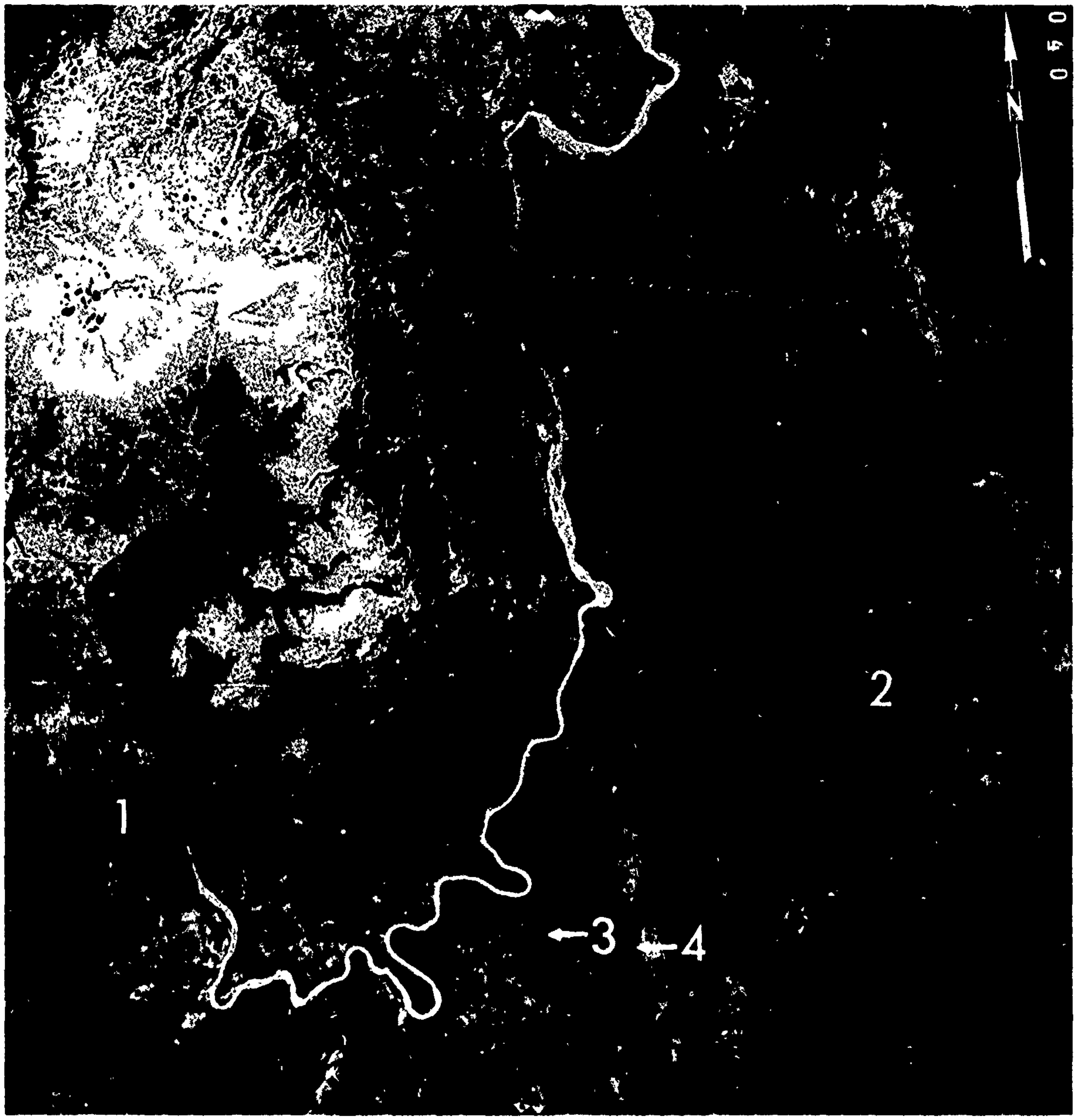


Figure 11. Area near the confluence of the Susitna (1) and Tyone (2) Rivers; lake 3 is marginally visible on the Landsat EDIES image, lake 4 is clear; taken on 28 July 1977 during NASA mission 364; scale, 1:160,000.

Cooper et al. (1975) reported that, with digital processing techniques, the computer compatible tapes (CCT) standard image data can show a circular lake with a minimum diameter of 148 m or 17,200 m² in area Graybeal et al (1974) reported that water bodies as small as 8000 m² can be identified occasionally on the CCT data for standard imagery. The CCT's for standard images contain all the Landsat radiometric data as acquired from the satellites Bands 4, 5 and 6 have 128 discernible levels of radiant energy, band 7 has 64 levels. These compare to 16 levels shown on standard Landsat images.

The improved EDIES imagery with 64 levels of radiant energy shows lakes of approximately the same size as can be delineated from standard image CCT data. If all the enhanced image data on CCT's used to produce EDIES images were analyzed, delineation of water bodies smaller than 8000 m² might be possible.

The following figures are shown for additional comparisons between the Landsat scene and the

Figure 12. Area between Maclaren River (1) and Dickey Lake (2) in northeastern part of basin; taken on 29 July 1977 during NASA mission 364, scale, 1:160,000.

NASA photographs Figure 11, NASA photograph 16-036, Figure 12, NASA photograph 19-058, and Figure 13, NASA photograph 19-056.

Glaciers and snowfields

The Landsat EDIES image showed more snowfields than I mapped since some of the fields appeared as specks too small to draw.

The color composite EDIES image (Fig 3) shows the difference between ice and snow and the surrounding terrain better than the black and white individual bands (Fig 4a-d) of the EDIES image, therefore, it is considered better for mapping the glaciers and snowfields The vegetation depicted by red tones and the bedrock in various shades of gray on the color composite contrasted well with the blue ice and white snow Differentiation of these features was generally easy.

Differentiation of snowfields and some small glaciers was difficult because portions of the glaciers are snow covered. However, I did not attempt to categorize the glaciers and snowfields based on size.

Figure 13. Clearwater Creek (1), Maclaren River (2), and Denali Highway (3); taken on 29 July 1977 during NASA mission 364; scale 1:160,000.

I separated the blue ice and snow-covered portions of the glaciers from the dirty ice zone at the glacial terminus. A gap between the glaciers (red) and the outwash plains (blue) below the glaciers on the south side of the Alaska Range can be seen in Figure 7.

The largest glaciers in the Upper Susitna River Basin occur in the Alaska Range From west to east, they are the West Fork, Susitna, East Fork, Maclaren, and Eureka Glaciers. These glaciers are the primary sources of meltwater and glacial sediment for the Susitna River

Smaller glaciers and snowfields occur in the Talkeetna Mountains, Clearwater Mountains, and mountains around Tsusena Creek on the northwest border of the basin The Talkeetna glaciers and snowfields are the sources of three Susitna River tributaries, Kosina Creek, Black River, and Oshetna River. The glaciers and snowfields in the Clearwater Mountains are the third largest in size, while those near Tsusena Creek are the fourth

Valley glaciers are constantly moving downslope, transporting eroded debris to their termini

Terminus of the West Fork Glacier (4), exposed ice (2), meltwater streams (3), debris at terminus (1), surface water (5), Nenana Glacier (6); taken on 29 July 1977 during NASA mission 364; scale 1:160,000.

where the debris is deposited. The terminal zone of a glacier is usually composed of poorly sorted sediment overlying ablating glacier ice. Because the zone is dynamic, I compared the Landsat EDIES image with NASA photographs acquired a year later rather than comparing it to topographic maps.

The distribution and large-scale relationships of debris (1, Fig. 14), exposed ice (2), and meltwater streams (3) at the terminus of West Fork Glacier (4) are similar on the Landsat EDIES image (Fig. 3) and NASA photograph 19-008 (Fig. 14). Surface water (5) on the surface of the terminus is also apparent on both, however, small-scale roughness is apparent only on the NASA photograph.

The lateral and medial moraines are well defined. Their patterns are evident on the Landsat image and NASA photographs. The patterns apparent on the Landsat EDIES image (Fig. 3) and NASA photographs 19-008 (Fig. 14), 19-012 (Fig. 15), and 19-010 (Fig. 16) show this comparison

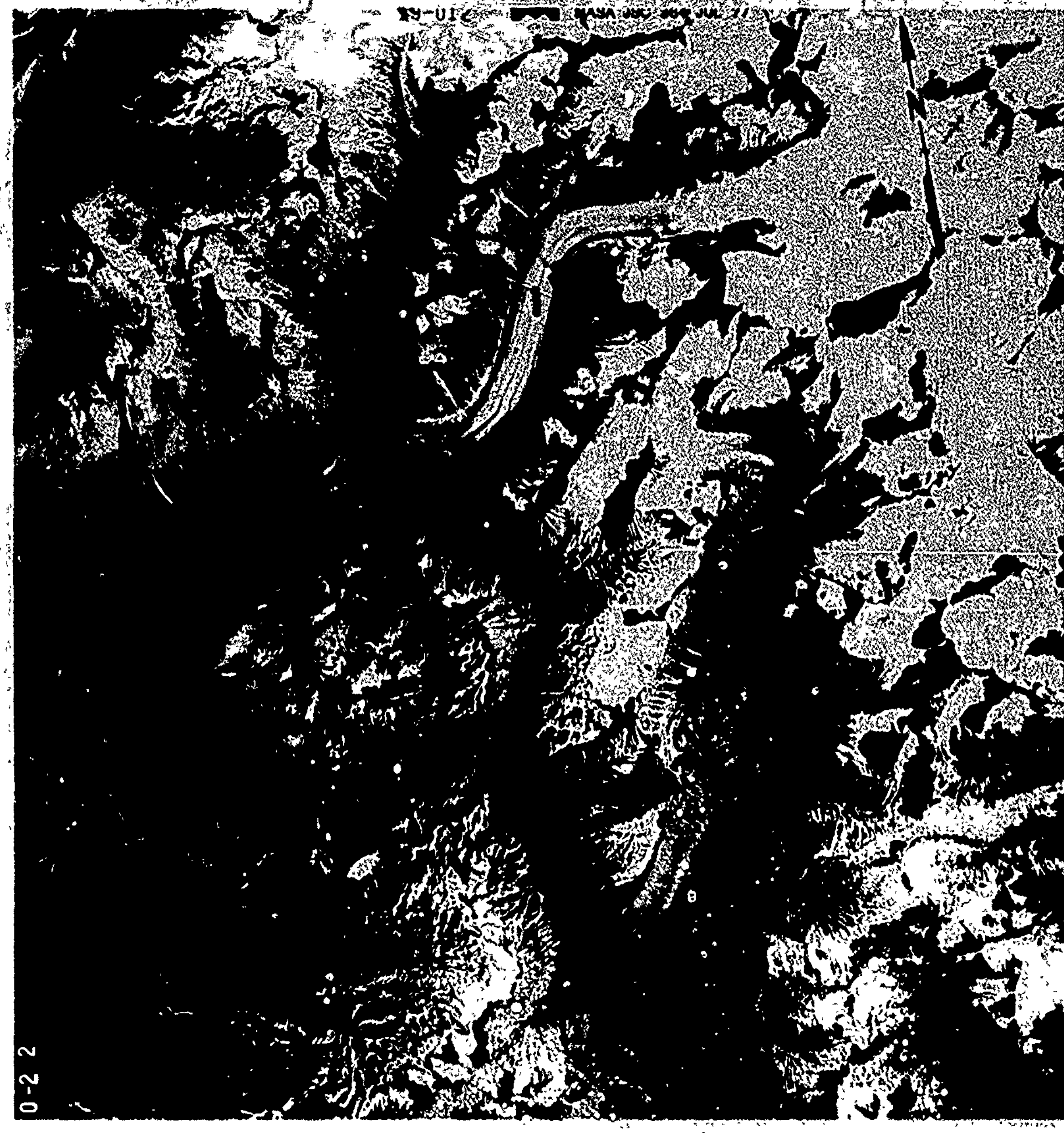


Figure 15. East Fork Glacier (1); taken on 29 July 1977 during NASA mission 364; scale, 1:160,000.

Conclusions

Landsat imagery provided useful information for delineating the major drainage patterns, the distribution of lakes and glaciers or snowfields, many geologic features at the termini of the large glaciers, and reflectivity differences of lakes and rivers. Also, many small lakes not shown on available 1:250,000 topographic maps were evident on the 1:250,000 Landsat imagery.

The imagery did not show the lakes much smaller than 8000 m^2 in area, some of the streams smaller than the resolution of the multispectral scanner (70×58 m), or a distinct shoreline for some of the small lakes.

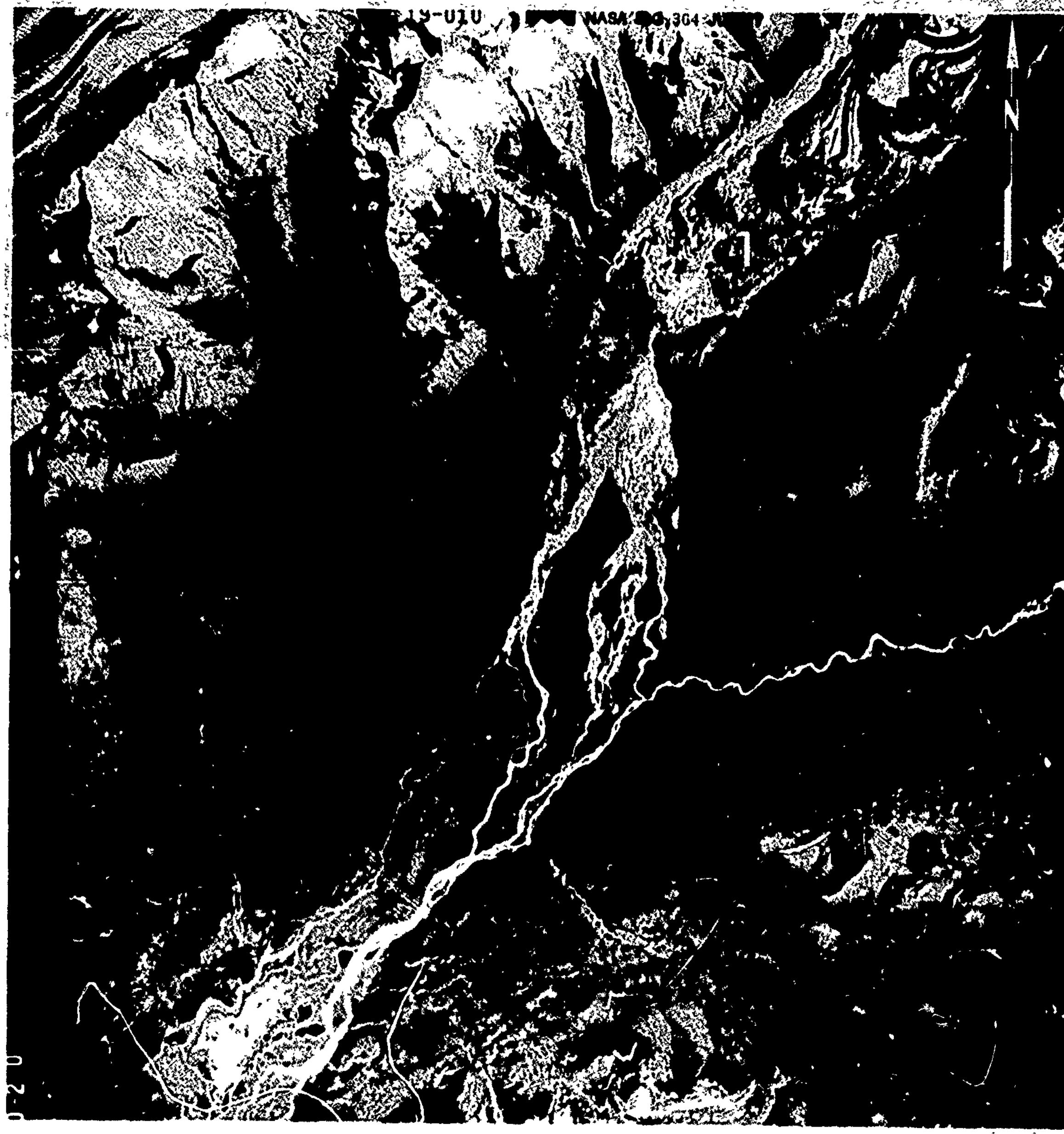


Figure 16. Terminus of the Susitna Glacier (1); taken on 29 July 1977 during NASA mission 364; scale 1:160,000.

Landsat imagery would be a useful tool for making initial large-scale maps and updating the maps showing river channel configuration and location, mid channel bars and islands, locations of river icings, lake distribution, location and features of the glacier terminus, changes in medial and lateral glacial moraines, and changes in river and lake sediment concentrations.

PART II. USE OF LANDSAT IMAGERY IN MAPPING AND EVALUATING GEOLOGIC LINEAMENTS AND POSSIBLE FAULTS.

Carolyn J. Merry

Objective

The primary objective of this part of the project was to prepare a lineament map of the Upper Susitna River Basin, including a 100-km radius of the proposed Devil Canyon and Watana dam sites.

Geologic structure*

Three joint sets, one well-developed and two poorly developed, occur in the Devil Canyon Dam site area. The strike of the well-developed joint set varies from N 45°W to N 10°W and averages N 25°W. The dip ranges from vertical to 75°E and averages 80°E. Average spacing of the joints is 1.2 to 1.5 m with local variations of 5 cm to as much as 4.6 m.

The two poorly developed joint sets consist of a tight set striking parallel or subparallel to the bedding, but dipping generally north, and an eastward-striking, nearly horizontal set. The first set has a spacing of 7.6 cm to 4 6 m and the second set has a spacing from 7.6 cm to 9.1 m. The joints in the second set are tight, dipping from 15°N to 15°S, with the dip more commonly being horizontal.

Well-developed shear zones striking N 25°W and dipping 80°E, spaced from 15 to 244 m, occur in the bedrock of Devil Canyon. The shear zones appear to have developed parallel to or along the same trend of the well-developed joint zone. The joint zone is probably older than the shear zones.

The dominant geologic structures at the Watana dam site are fractures which strike N 40-60°W and dip to the northeast from 70° to vertical.**

*Section based on a report by Kachadoorian (1974)

**J K Soper, Alaska District Corps of Engineers, personal communication (1979)

Methods

Cloud-free early winter scenes were selected for the lineament mapping. The conditions of light snow cover and low sun angle accentuated lineaments. The four Landsat-1 MSS band 7 images which were used in the photomosaic were obtained on 2 and 4 November 1972 (NASA scene ID numbers: 1102-20450, 1102-20452, 1104-20563 and 1104-20565).

The site location map (Fig. 17) shows the location of the Devil Canyon and Watana dam sites, a 100-km radius around each dam site, the Susitna River basin boundary, and selected significant places. Definitions of selected geologic terms used in interpreting the maps are contained in the *Glossary*.

Results

Geologic lineaments

A lineament map was prepared for the Upper Susitna River Basin from the Landsat black and white photomosaic at an original scale of 1:250,000 (Fig. 18). There are many more lineaments evident on the Landsat photomosaic than shown on Figure 18. Only those lineaments related to reported tectonics were mapped. Therefore, this lineament map differs from previous lineament maps for the area which usually included all lineaments. Lineaments aligned in the NE-SW and NNW-SSE directions were included in Figure 18. Lineaments in the E-W direction were not mapped.

Three major periods of deformation are recognized in the Talkeetna Mountains, a major portion of the Upper Susitna River Basin. These include: 1) a period of intense metamorphism, plutonism and uplifting in the late Early to Middle Jurassic, the plutonic phase of which persisted into Late Jurassic; 2) a Middle to Late Cretaceous alpine-type orogeny, the most intense and important of the three, and 3) a period of normal and high-angle reverse faulting and minor folding in the Middle Tertiary, possibly extending into the Quaternary (Csejtey et al. 1978).

There is a dominant NE-SW striking structural trend in the Talkeetna Mountains-Alaska Range

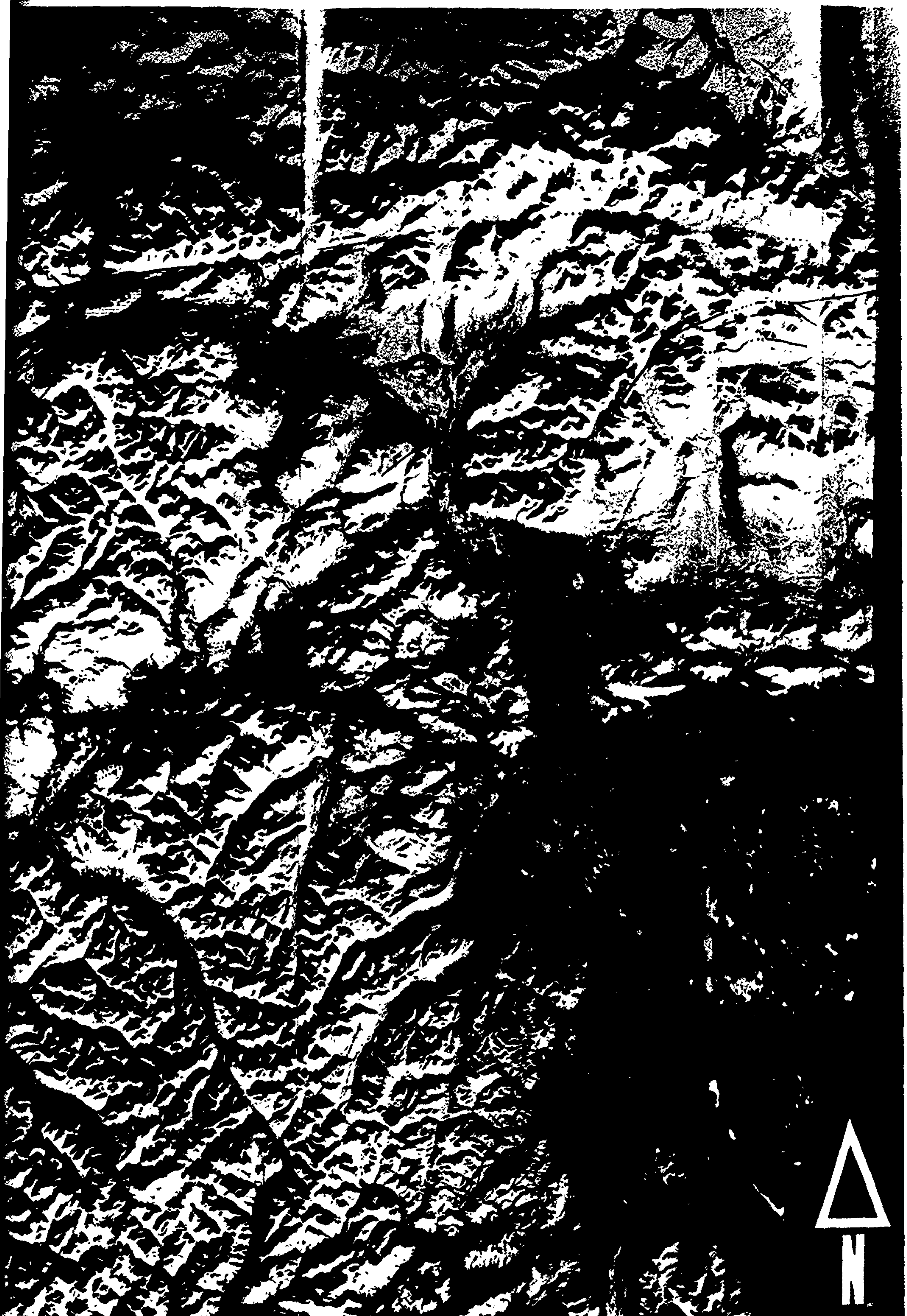

(62 st. mi)
CANYON

Figure 17 Site location
Susitna River Basin, Alaska

0 10 20 30
0 10 20


N


DENALI



LEGENI

Fault, approx loc where concealed

Right lateral disp

Thrust fault (teetl thrown side)

Postulated thrust

Figure 19 Known fa Susitna River Basin, 1974, Beikman et al Lahr and Kachadoorıa

0 10 20

0 10

complex as a result of the Cretaceous orogeny (Csejtey et al. 1978, Gedney and Shapiro 1975). It was also found that several strong lineaments intersect the Denali fault from the southwest (Gedney and Shapiro 1975). One lineament follows the southeast margin of the Alaska Range and intersects the Denali fault near Windy. A second lineament parallels this about 60 km to the east and intersects the Denali fault in the depression occupied by the Susitna Glacier.

The secondary set of lineaments in the study area strikes in a NNW-SSE direction. The principal examples are the valleys of the upper Talkeetna River and the Sheep River. These lineaments are considered to be elements of the same fracture system and, therefore, subject to the same level of seismicity (Gedney and Shapiro 1975).

The E-W lineaments do not occur often, which tends to cast doubt on the fact that the Susitna River course is fault-controlled (Gedney and Shapiro 1975).

Known faults

The regional faults of the area were mapped on the black and white Landsat photomosaic (Fig. 19)

The Denali fault is located less than 80 km north of the Devil Canyon and Watana dam sites, and the Castle Mountain fault is located to the south These faults have been fully documented in the field and are known to be large-scale right-lateral strike-slip faults (Gedney and Shapiro 1975). The Denali fault shows evidence of a 3-cm/yr average slip rate during the Holocene and could sustain a magnitude* 8.0 event on the Richter scale (Lahr and Kachadoorian undated, Gedney and Shapiro 1975). The Denali fault was formed by renewed northwestward plate motion in the northern Pacific plate since mid-Tertiary time (Richter and Jones 1973).

A fault had been proposed by Gedney and Shapiro (1975) starting at the Susitna Glacier on the north to south of the Talkeetna River. However, reconnaissance work in the Talkeetna Mountains quadrangle during the summer 1977 showed no evidence of this ** In fact, evidence for recent fault movements was not found near the Susitna River within the Talkeetna Mountains quadrangle (Csejty et al. 1978).

A major structural boundary is a line of faults that extends northeast within the Talkeetna Mountains quadrangle area. The most prominent fault of this set is called the Talkeetna thrust of Cretaceous age (Csejtey et al. 1978). The Talkeetna thrust has placed Paleozoic, Triassic and, locally, Jurassic rocks over Cretaceous sedimentary rocks. Another Cretaceous feature is an intense shear zone, which is locally as much as 25 km wide, southeast of the Talkeetna thrust (Csejtey et al. 1978).

There are two poorly exposed normal faults as a result of a Cenozoic deformation in the Chulitna River valley; other Cenozoic faults have not been found within the Talkeetna Mountains quadrangle (Csejtey et al. 1978).

There is an apparent graben formed by the western flanks of the Talkeetna and Chugach Ranges and the eastern flank of the Alaska Range. Cretaceous to Recent faulting and shearing has occurred in this area (Lahr and Kachadoorian undated).

Activity of other faults in the Upper Susitna River Basin is uncertain and the shallow seismicity data are too scattered to determine any association with individual faults. Shorter faults and shear zones trending at high angle to the northeast structural trend have been identified in certain mapped parts of the Upper Susitna River Basin, and it has been assumed that similar structures along this trend may be common (Gedney and Shapiro 1975) Evidence of recent faulting has not been reported, possibly because of the lack of mapping (Gedney and Shapiro 1975).

Csejtey et al. (1978) present a detailed discussion of the geologic units and faults found in the Talkeetna Mountains area

Epicenters

The proposed Devil Canyon reservoir area is located in the tectonic zone which extends along the entire margin of the Pacific plate (Fig. 20). The Pacific plate is moving northwestward with respect to the North American plate (Lahr and Kachadoorian undated). Three types of seismicity events are associated with plate tectonic movement: 1) earthquakes, such as the 1964 Alaskan earthquake with a Richter magnitude of 8 3 to 8.75, that occur on the surface of contact between the Pacific plate and the North American plate, 2) earthquakes that occur in the

*See definition of earthquake magnitude in the *Glossary* Magnitude in this report will be expressed in terms of the Richter scale The Modified Mercalli scale is used to describe earthquake intensity

**B Csejtey, Jr, U S Geological Survey, personal communication (1979)

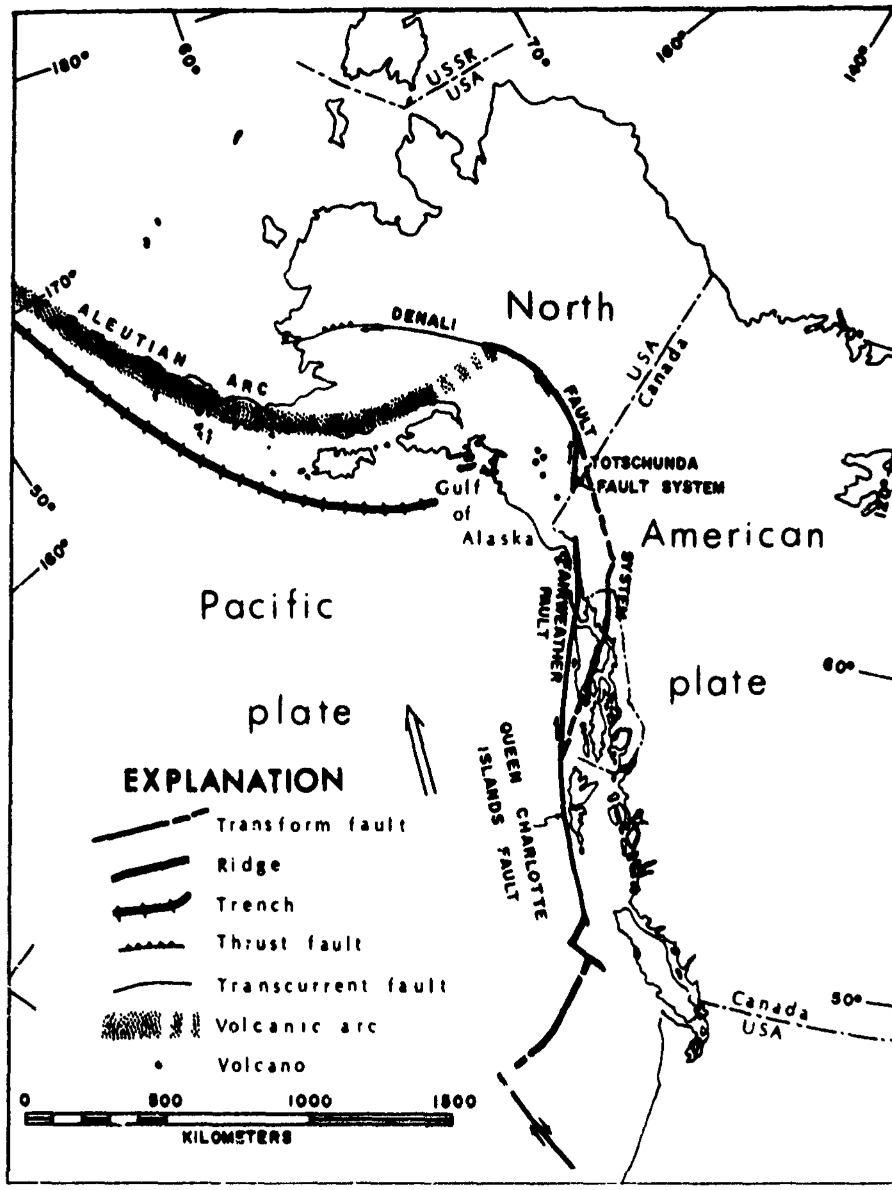


Figure 20. Map of northwestern North America showing major tectonic features (after Richter and Matson 1971, Tobin and Sykes 1968).

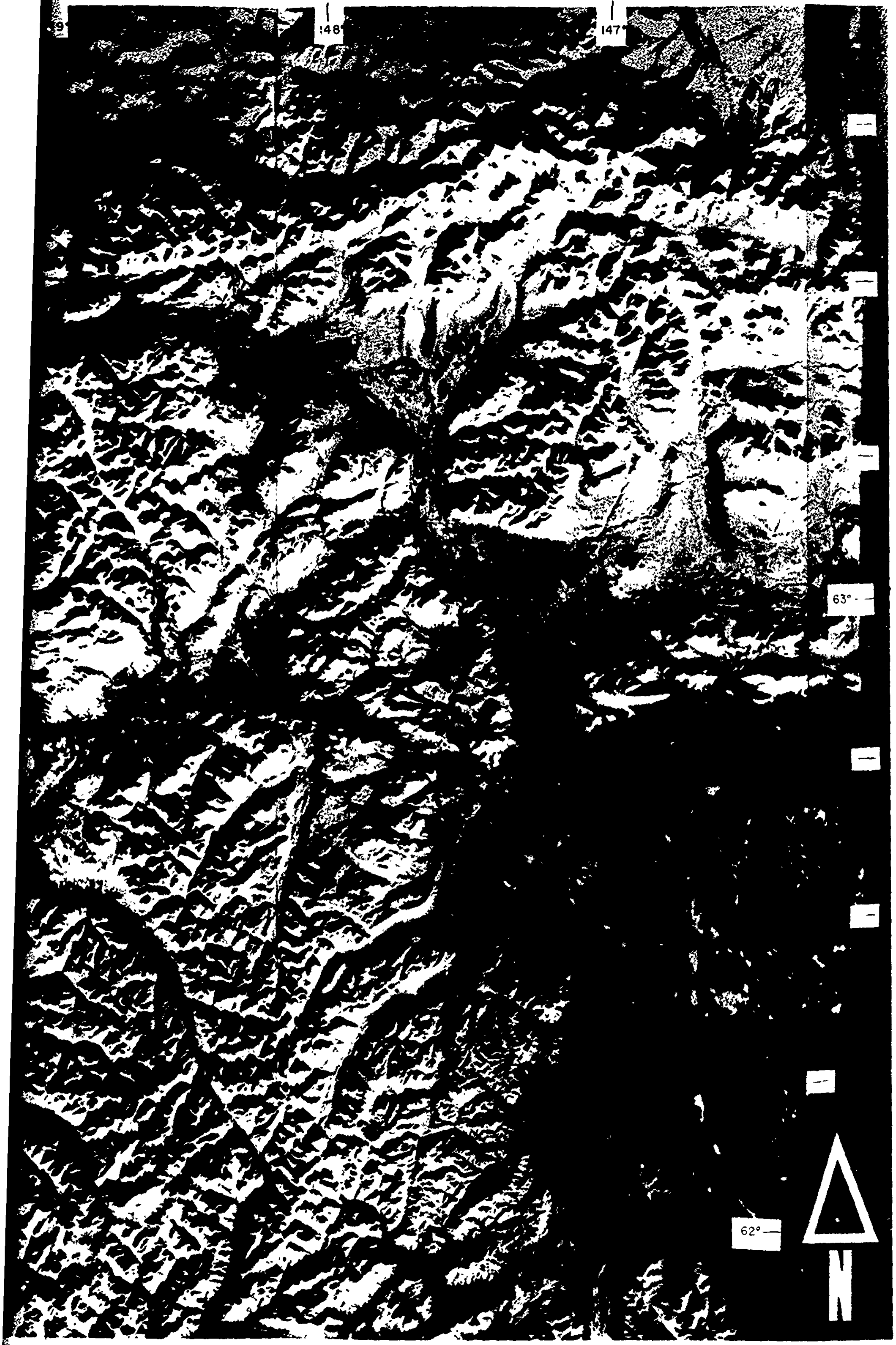
North American plate in response to stresses produced by interaction with the Pacific plate, and 3) earthquakes that occur in the Benioff seismic zone* of the Pacific plate, which is being thrust below Alaska

The oceanic crust of the Pacific plate is actively underthrusting the North American plate along the Aleutian volcanic arc (Fig. 20) (Isacks et al. 1968, McKenzie and Parker 1967, Plafker 1969, Richter and Matson 1971). Southern Alaska between the eastern limit of underthrusting along the Aleutian Arc (at about 145°W) and the southeast part of the Denali fault system is largely uncoupled from the North American plate and moving with the Pacific plate (Richter and Matson 1971).

The epicenter map prepared for the Upper Susitna River Basin shows the location of epicenters from 1 March 1975 to 14 October 1976

*See definition in *Glossary*


151°
150°
149°
63°
62°



LEGEND

		Magnitude		
		0-2.9	3-4.9	5-7
D	0-24.9	•	●	●
e	25-49.9	■	■	■
p t	50-99.9	◆	◆	◆
h	100-200	▲	▲	▲
(km)				

Figure 21 Epicenter locati
Upper Susitna River Basin, A

0 10 20 30
0 10 20

for a 100-km radius of each of the proposed dam sites (Fig. 21). The epicenter locations were obtained from the earthquake data file prepared by the National Geophysical and Solar-Terrestrial Data Center, Environmental Data Service, National Oceanic and Atmospheric Administration. In addition, other earthquakes located outside the 100-km radius were plotted in Figure 21 to provide a regional perspective of seismicity for the study area.

The epicenter map (Fig. 21) updates a previously prepared seismicity map (Lahr and Kachadoorian undated). Earthquakes shallower than 50 km are not associated with the Benioff seismic zone. The epicenters at a 33-km depth usually lack depth control and may be deeper than 50 km. Seismicity in the region of the proposed reservoirs ranges in depth from less than 10 km to greater than 175 km (Lahr and Kachadoorian undated). Seismic activity deeper than 50 km is postulated to be associated with the Benioff zone of the underthrusting Pacific plate.

Table 2 is a tabulation of the earthquakes which occurred within the 100-km radius of the Devil Canyon and Watana dam sites. These earthquakes include those with a Richter magnitude of 4.0 or greater occurring from March 1975 through December 1977 There were a total of 52 earthquakes of Richter magnitude ≥ 4.0 which occurred during this time interval. Most earthquakes were recorded at Richter magnitudes between 4.1 and 4.9 at depths generally greater than 50 km. These earthquakes are associated with the Benioff seismic zone of the Pacific plate An earthquake with a Richter magnitude of 5.7 was recorded on 18 May 1975. The earthquake occurred at a relatively deep depth (96 km) and is also associated with the Benioff seismic zone

The nearest earthquake to the Devil Canyon dam site with a Richter magnitude greater than 4.0 was recorded at a distance of 21 km The magnitude of this earthquake was 4.9 on the Richter scale. The farthest earthquake within the 100-km radius area was recorded at a distance of 100 km with a 4 5 Richter magnitude Both earthquakes were the type associated with the Benioff seismic zone.

The nearest earthquake to the Watana dam site was recorded at a distance of 36 km with a 4.9 Richter magnitude. The farthest earthquake within the 100-km radius was recorded at 98 km with a 4.2 Richter magnitude. Again, both earthquakes were the type associated with the Benioff seismic zone

There were 62 earthquakes recorded with a local Richter magnitude less than 4.0 from March 1975 through December 1977. The closest earthquake to the Devil Canyon and Watana dam sites was recorded at distances of 16 km and 12 km, respectively, with a Richter magnitude of 3.8.

Earthquakes occur mainly near Mt. McKinley (Fig. 20). These earthquakes result as a direct response to the subduction of the North Pacific lithospheric plate (VanWormer et al. 1974). The seismicity is generally rather deep and poses no genuine hazard to any existing structures or settlements (Gedney and Shapiro 1975). Deeper earthquakes also occur along the subduction zone extending southward from Mt. McKinley, but these are unlikely to be large enough to cause extensive damage. Eastward of the Mt. McKinley area the seismicity is relatively shallow and confined generally to the upper part of the lithosphere (Gedney and Shapiro 1975).

Conclusions

A lineament map was prepared of the Upper Susitna River Basin using Landsat photointerpretation techniques. Also, maps were prepared, based on a review of the literature, of known faults and epicenter locations in the Upper Susitna River Basin

There is a dominant NE-SW striking and secondary NNW-SSE striking set of lineaments in this region. The dominant lineaments within the 100-km radius of the Devil Canyon and Watana dam sites are associated with the following tectonic origins: 1) lineaments associated with the Denali fault; 2) lineaments associated with the zone of Cretaceous to Recent faulting and shearing; and 3) lineaments associated with and to the east of the Talkeetna thrust.

The literature to date, field reconnaissance and epicenter activity indicate that recent fault activity has not occurred in the Devil Canyon and Watana dam site area.

The epicenter map shows that 52 earthquakes of a Richter magnitude ≥ 4 0 occurred between March 1975 through December 1977 Most earthquakes were found to occur in the Mt. McKinley area, as a direct response to the subduction of the North Pacific lithospheric plate The nearest reported earthquake found in this study to the Devil Canyon and Watana dam sites was at a distance of 16 km and 12 km, respectively, with a Richter magnitude of 3 8

Table 2. Compilation of earthquakes with a Richter magnitude ≥ 4.0 from March 1975 through December 1977 within a 100-km radius of the Devil Canyon and Watana dam sites.

Date	Latitude (°N)	Longitude (°W)	Depth (km)	Magnitude	Distance from Devil Canyon (km)	Distance from Watana (km)
11 Mar 75	63.1	148.8	58	4.1	42	37
18 Mar 75	63.3	150.6	129	4.6	82	115
19 Mar 75	62.8	150.6	77	4.6	66	105
20 Mar 75	63.2	150.7	130	4.9	83	119
20 Mar 75	63.2	149.2	75	4.5	46	55
23 Mar 75	63.1	151.0	130	4.6	90	128
24 Mar 75	63.2	150.8	133	4.4	84	119
26 Mar 75	63.0	150.5	92	4.2	64	102
13 Apr 75	63.3	149.7	96	4.6	62	83
19 Apr 75	62.8	151.2	114	4.2	95	134
21 Apr 75	62.9	151.3	116	4.5	100	139
16 May 75	62.9	149.9	68	4.3	31	70
17 May 75	63.1	150.8	123	4.0	79	116
18 May 75	63.0	150.1	96	5.7	44	81
20 May 75	62.9	150.1	131	4.6	42	80
29 May 75	63.2	150.1	54	4.0	56	87
11 Jun 75	62.1	149.5	41	4.5	81	95
22 Jun 75	63.0	150.0	64	4.1	36	73
24 Jun 75	62.9	150.8	103	4.6	76	115
11 Jul 75	63.1	150.7	143	4.6	76	113
8 Aug 75	63.2	150.5	124	4.6	74	107
10 Aug 75	63.2	150.4	129	4.6	68	102
17 Sep 75	63.4	149.7	101	4.4	67	87
29 Sep 75	62.8	151.1	105	4.1	92	131
29 Sep 75	63.4	150.3	79	4.1	79	108
30 Sep 75	63.2	150.4	128	4.7	70	104
21 Oct 75	63.0	150.8	109	4.1	77	115
25 Oct 75	63.3	150.8	114	4.1	90	124
25 Oct 75	63.4	149.9	80	4.1	74	97
26 Dec 75	62.4	150.0	46	4.1	49	78
29 Dec 75	62.4	148.6	33	4.2	65	52
19 Feb 76	63.1	149.6	91	4.4	37	62
13 Mar 76	63.5	148.7	22	4.2	82	76
26 Mar 76	63.6	147.6	33	4.2	121	98
11 Jul 76	63.2	150.7	120	4.7	82	117
21 Aug 76	62.9	150.9	119	4.1	81	120
27 Aug 76	62.3	149.4	51	4.3	59	74
16 Sep 76	62.9	150.3	97	4.3	51	91
19 Sep 76	63.0	151.2	132	4.5	96	135
18 Oct 76	63.3	150.7	126	4.9	89	122
24 Oct 76	62.6	149.1	75	4.9	21	36
3 Nov 76	63.1	151.0	133	4.4	88	125
4 Dec 76	63.2	150.8	129	4.3	86	122
15 Jan 77	62.8	150.4	100	4.3	54	93
5 Mar 77	63.2	150.5	122	4.2	75	108
20 Apr 77	62.8	151.0	114	4.5	88	127
1 May 77	63.2	150.9	134	4.0	89	125
6 Jun 77	62.2	149.5	60	4.1	74	89
23 Aug 77	63.7	149.4	126	4.1	100	108
9 Sep 77	62.2	149.5	59	4.6	71	86
19 Oct 77	62.9	150.6	102	5.0	63	102
20 Nov 77	62.4	150.7	79	4.9	81	116

PART III. USE OF LANDSAT IMAGERY IN MAPPING SURFICIAL MATERIALS

SECTION A. LANDSAT MAPPING

Harlan L McKim

Objective

The objective of this part of the study was to prepare a surficial geology map of the Upper Susitna River Basin from a color composite of Landsat imagery

This study was initiated to evaluate the utility of the Landsat data products for Corps of Engineers' soils and geology requirements. The surficial geology map should provide information on the types of material in each unit, provide a large-scale map that can be used in selection of drilling sites, provide a basis for estimating transportation cost of material to the dam site and serve as an existing data base for selection of further low-altitude photographic missions

It was assumed that the imagery could provide an adequate amount of information in remote areas where ground truth data were not available or would be very costly to obtain for the early planning stages of a project.

General geology

The status of geologic mapping in the Upper Susitna River Basin is shown in Table 3.

Argillite, graywacke, metagraywacke and slate of probable Cretaceous age underlie the proposed Devil Canyon Dam site. The units are exposed along the Susitna River from a point about 24 km north of Talkeetna almost to the mouth of Tsusena Creek, and in scattered outcrops throughout the proposed reservoir area (Csejtey 1974, Lahr and Kachadoorian undated). This rock unit consists of hard, generally massive, medium- to dark-gray metamorphosed fine-grained sediments that contain numerous stringers and vugs of quartz (Kachadoorian 1974) Major structures in these rocks are a series of isoclinal folds striking to the northeast (Capps 1940).

The bedrock at the Watana dam site consists of a crystalline (diorite) pluton intruded into older Tertiary sediments of shales and argillites with some Tertiary volcanic flows.*

Two diorite and granodiorite bodies of Late Cretaceous to Early Tertiary age, which are similar to the Talkeetna Mountains batholithic complex, have been mapped within the southern half of the zone of metasedimentary rocks (Gedney and Shapiro 1975). Several irregular bodies of granite and granodiorite of Tertiary age have also been mapped along the western flank of this zone and an extensive area of these rocks occurs about 32 km to 64 km north of the Susitna River (Gedney and Shapiro 1975).

Glacial moraine is the predominant surficial geology unit in this area (Kachadoorian 1974). Evidence from glacial striae, topographic maps and aerial photographs indicates that the glacier moved westward across the area (Kachadoorian 1974). Unconsolidated materials deposited by alluvial, glacial, swamp and lacustrine processes during the Pleistocene and Holocene times occur throughout the region (Gedney and Shapiro 1975).

Methods

An EDIES color composite at a scale of 1:250,000 was used as the photo data base for the surficial geology mapping. The color composite was purchased from EROS Data Center, Sioux Falls, South Dakota, for $1000. An acetate overlay was used for the mapping exercise. Adequate ground truth information was not available, but some exploratory soil survey information within or in the proximity of one area was available (Reiger et al. 1979). This exploratory soil survey was placed over the photomosaic as shown in Figure 22.

The mapping units selected were differentiated by geomorphic position, inferred slope, vegetative patterns and lake density. The tone and texture changes on the imagery indicated that these parameters, even though not implying genetic differences, could be separated Because the resolution of the Landsat imagery is about 58×70 m, objects smaller than this size

*J K Soper, Alaska District, Corps of Engineers, personal communication (1979)

Table 3. Previous geologic mapping in the Upper Susitna River Basin, Alaska.

Source	*Area mapped*
S.R. Capps (1940)	Talkeetna Mountains
B. Csejtey (1974)	Talkeetna Mountains (Watana Lake area, C-4 quadrangle, A-5 quadrangle) (1974)
B Csejtey et al (1978)	Talkeetna Mountains quadrangle (1978)
H M. Beikman (1974)	Southeast Quadrant of Alaska
T E. Smith and D L Turner (1974)	Area north and west of 62°40'N/ 148°45'W, including northeastern part of the Talkeetna Mountains quadrangle
R.G Forbes et al (1974)	Discussion of geochronology and tectonics of above area
R. Kachadoorian (1974)	Devil Canyon dam site
L. Lahr and R Kachadoorian (undated)	Devil Canyon and Watana Reservoir areas
H.M. Beikman et al. (1977)	Eastern part of southern Alaska

cannot be seen on the imagery unless they contrast significantly from the surrounding terrain.

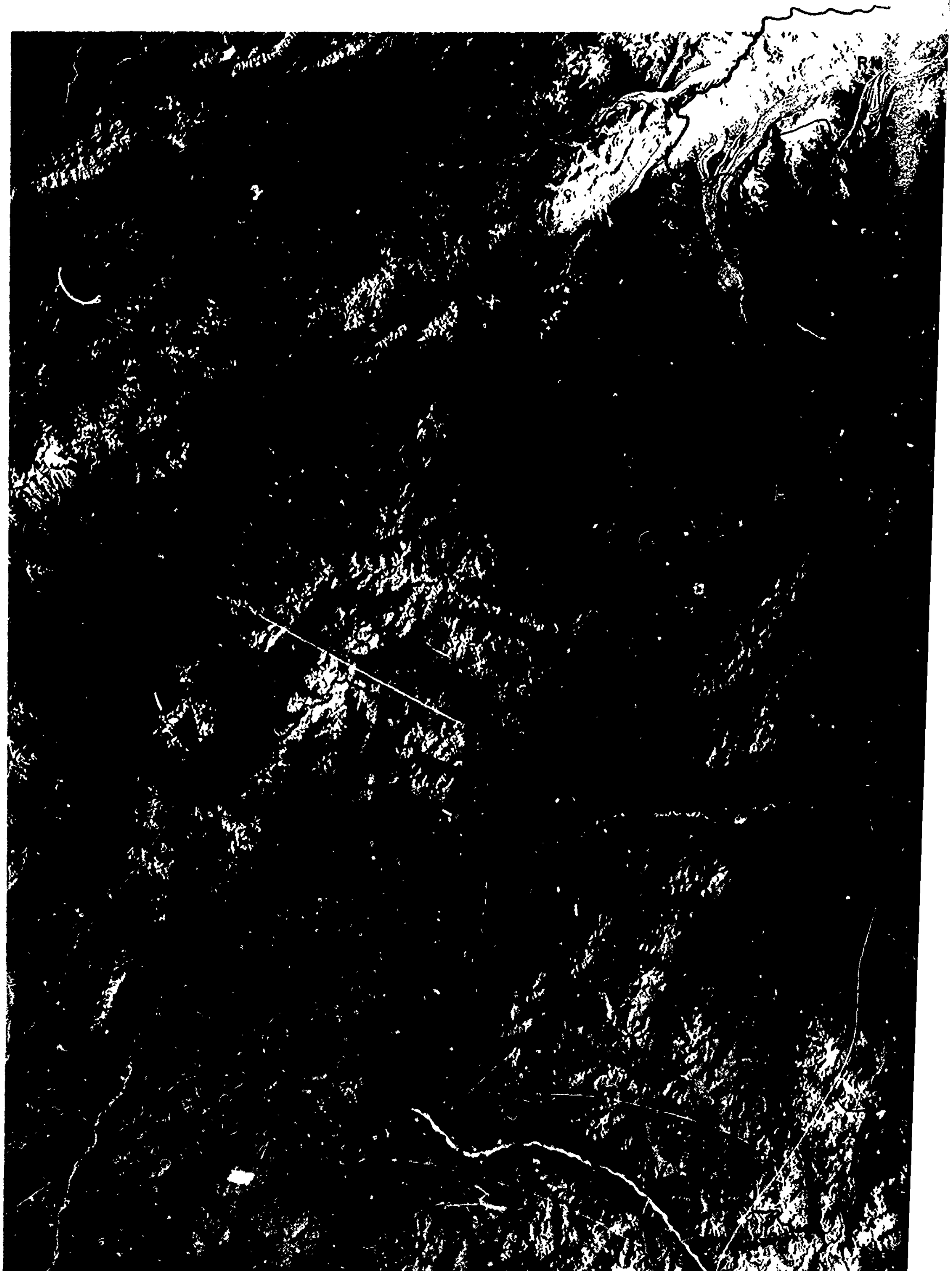
An important aspect in determining the number of delineations to be made is the time and cost involved in the study for the amount of information that can be obtained from the imagery. The need for information from Landsat imagery generally arises during preliminary investigations where adequate ground truth is not available. A single Landsat scene covers about 185×185 km and costs $8 for a 22.8-cm print. The time involved in mapping the surficial geology on the Landsat scene for this study was less than two weeks. Therefore, much geologic information in a remote area can be quickly and cost-effectively obtained.

Results

Careful examination of the color composite resulted in the mapping of six surficial geology units (Fig. 23). The descriptions of the units are as follows:

b	in-situ bedrock and very coarse bedrock colluvium primarily confined to steep slopes and mountain crestlines, bedrock exposures > 75%
bc	coarse- to fine-grained deposits occurring on moderate to steep slopes in mountainous terrain and rolling uplands that have minor scattered bedrock exposures restricted to the uppermost slopes and crestlines, bedrock exposures < 75%
ag	undifferentiated alluvial-glaciofluvial deposits associated with gentle to moderate backslope and footslope positions; fine- to coarse-grianed alluvial fan, terrace, stream and eolian deposits derived from reworked glacial and alluvial deposits, morainal deposits, till, and outwash gravels and sands, occurring in part on modified morainal topography and large alluvial terraces
fl_1	undifferentiated fluvial-lacustrine deposits, fine- to medium-grained sands and silts associated with modern and abandoned floodplains and low-lying terraces, possibly including eolian sands and silts, generally poorly drained.
fl_2	same as fl_1, except for fewer lakes and not as poorly drained
um	unvegetated moraines

Tones and texture plus the use of minimal stereo coverage aided in this analysis. It was relatively easy to differentiate the *L* and *bc* units. The dark grey colors in the mountainous



LEGEND

SO10 Humic Cryorthods, hilly to steep, very gravelly

SO12 Humic Cryorthods, hilly to steep, very gravelly and Terric Cryohemists

SO15 Pergelic Cryorthods and Histic Pergelic Cryaquepts, nearly level to rolling, very gravelly

SO16 Pergelic Cryorthods, hilly to steep, very gravelly, and Histic Pergelic Cryaquepts, nearly level to rolling, loamy

SO17 Pergelic Cryorthods, hilly to steep, very gravelly and rough mountainous land

RM1 Rough mountainous land

EA2 Typic Cryaquepts, nearly level, sandy

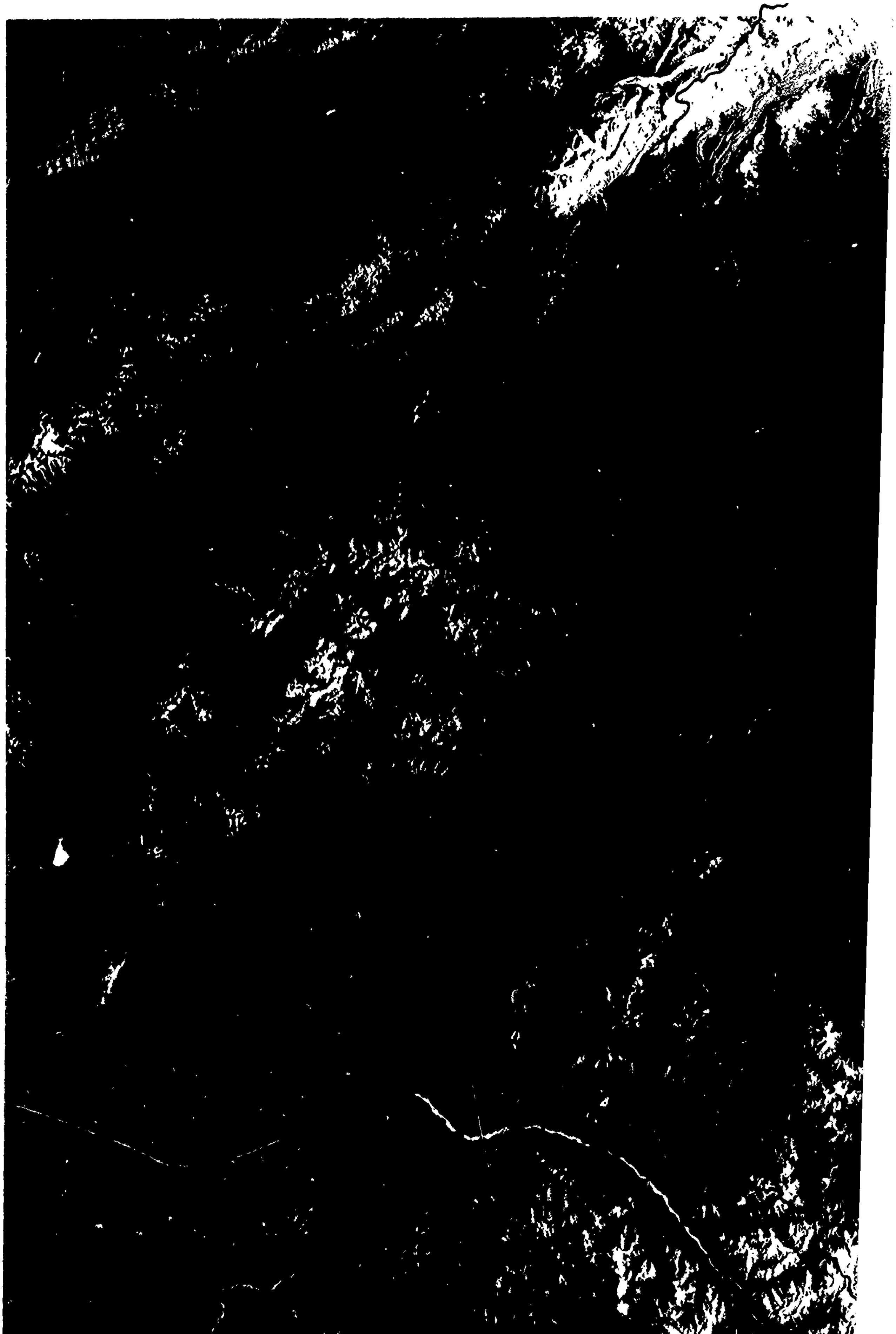
IQ1 Histic Pergelic Cryaquepts, nearly level to rolling, clayey

IQ2 Histic Pergelic Cryaquepts, nearly level to rolling, loamy

IU2 Pergelic Cryumbrepts and Histic Pergelic Cryaquepts, hilly to steep, very gravelly

IU3 Pergelic Cryumbrepts, hilly to steep, very gravelly, and rough mountainous land

Figure 22. Exploratory soil survey map of the Upper Susitna River Basin, Alaska (from Rieger et al. 1979). (Registration of colored overlay is not accurate everywhere on base photograph because of material shrinkage.)



LEGEND

- b — In-situ bedrock and very coarse, rubbly bedrock colluvium primarily confined to steep slopes and mountain crestlines; bedrock exposures > 75%.
- bc — Coarse- to fine-grained deposits occurring on moderate to steep slopes in mountainous terrain and rolling uplands which have minor scattered bedrock exposures restricted to the uppermost slopes and crestlines; bedrock exposures < 75%.
- ag — Undifferentiated alluvial-glaciofluvial deposits associated with gentle to moderate backslope and footslope positions; fine- to coarse-grained alluvial fan, terrace, stream, and eolian deposits derived from reworked glacial and alluvial deposits, morainal deposits, till, and outwash gravels and sands; occur in part on modified morainal topography and large alluvial terraces.
- fl$_1$ — Undifferentiated fluvial-lacustrine deposits; fine- to medium-grained sands and silts associated with modern and abandoned floodplains, and low-lying terraces; may include eolian sands and silts; generally poorly drained.
- fl$_2$ — Same as fl$_1$ except for fewer lakes and not as poorly drained.
- um — Unvegetated moraines.
- ● — Field sites (37).

Figure 23. Surficial geologic materials as mapped from Landsat imagery and field site locations. (Registration of colored overlay is not accurate everywhere on base photograph because of material shrinkage.)

areas defined the *b* unit quite well, but the *b* unit was in part snow-covered. The *bc* unit occurs downslope from the *b* unit. The colors associated with this delineation included lighter blue and some faint reddish tones. Due to the scale of the imagery, some of the upper tributaries of streams were included within this unit. The *ag* unit included the rolling and hummocky upland areas defined by the light red and pink colors on the imagery. The fl_2 unit occurred in the lower-lying areas adjacent to streams. The fl_1 areas were bluish red and contained large areas of open water. It was assumed that these areas would be poorly drained. The fl_2 unit was dark red and occurred in floodplains and side slope positions. When this unit was mapped adjacent to large rivers, it included not only sections of the floodplain but included some of the transitional zone between *ag* and fl_2.

The material size associated with each unit was estimated from knowledge gained from other studies where ground truth had been available to test the relationship of material size to surficial geology units (McKim and Merry 1975). Since the map was prepared without the aid of ground truth only rough estimates of material size can be made.

SECTION B. FIELD EVALUATION

Daniel E. Lawson

Objectives

I examined the surficial geology of selected field sites in the Upper Susitna River Basin to.

1 Evaluate the accuracy and distribution of the mapping units used in the Landsat-derived surficial materials map

2 Determine the limitations of the interpretation technique and Landsat imagery for delineating geologic materials

3.Evaluate the potential usefulness of Landsat imagery interpretation for environmental mapping

Field investigations were done independently ot McKim's interpretations of the surficial materials from Landsat imagery (Part IIIA). Because the interpretation of Landsat imagery is still developing and somewhat limited, such field investigations are necessary to precisely define the types of materials and thus to develop a data base for interpreting that imagery

Methods

I reconnoitered the entire upper basin by helicopter over three days in the summer of 1978 to obtain an overall perspective of the basin geology, and then examined the surface and near-surface materials in detail at sites located mainly along the Denali Highway and Susitna River (Fig. 23). These sites represent terrain covered by each mapping unit and major textural and color variations evident in the Landsat image.

High-altitude aerial photographs (scale 1:60,000 and 1:130,000) and ground traverses defined the geologic setting of each site. Wherever possible, I examined outcrops or dug a shallow trench to determine the texture, sorting, density, color and other physical properties of the unconsolidated sediments. The relationship of the deposit to landforms was also determined.

I extrapolated the information from these limited site observations to other parts of the basin by referring to reports on the surficial geology of parts of the basin. The surficial geology of the Upper Susitna River Basin is not well known. Most of the older investigations (e.g. Moffit 1912, Capps 1940) were reconnaissance surveys conducted by the USGS. More recently, Kachadoorian et al. (1954), Kachadoorian and Péwé (1955), Kachadoorian (1974) and Csejtey et al. (1978) mapped the surficial and bedrock geology of parts of the basin in more detail.

I then compared th. results of the field investigations to the Landsat-derived map of the surficial materials and attempted to reconcile differences between the field data and the Landsat interpretation of the field sites. However, the precise boundary locations of each mapping unit were not checked.

Results

During the aerial observations I determined that, in general, the exposed bedrock regions in the basin (map unit *b*, Fig. 23) were accurately mapped but that the unconsolidated deposits were much more complex than the Landsat-derived surficial materials map indicated Therefore, my field efforts concentrated on sites located primarily in the Landsat-derived map units for unconsolidated deposits (Fig. 23).

These field observations also suggested that areas of till and related deposits of similar texture and sorting were not sufficiently distinctive on the Landsat imagery to have been recognized and mapped This is surprising because they

cover large areas of the basin and are generally recognizable on low altitude aerial photographs.

Map unit bc

The small number of sites examined in the *bc* map unit contain mostly numerous bedrock outcrops and mainly coarse-grained deposits (Fig. 23). Most of the unconsolidated deposits in this unit are either tills and materials with similar texture or colluvial material, or talus from adjacent mountain slopes. Boulders may protrude through the surfaces of these materials The topography at the field sites in this unit range from steep slopes to rolling upland with a rough surface. The Landsat mapping unit description generally represents the surficial materials at these sites, but does not include a description of the morainal materials

Map unit ag

The deposits at field sites located along the Susitna River near the proposed dam sites and along the Denali Highway in map unit *ag* indicate that the map unit description is inaccurate. Deposits at 8 of the 10 sites consist mostly of fine- to coarse-grained till and other sediments with similar texture and sorting (Fig 24). These sediments were sometimes observed interspersed with mainly glaciofluvial deposits Also, loess, a wind-blown silt deposit, was sometimes present as a thin (< 0.5-m) veneer. Alluvial fan deposits are present below the mouths of narrow mountain valleys

The terrain of most sites is gently rolling to hummocky upland with a moderate to locally steep slope. Well-developed lateral moraines and kame terraces occur on slopes in several locations. Boulders protruding through the surface of the tills locally roughen the surface.

Comparison of the geology at six sites to that shown on maps prepared by Kachadoorian et al (1954), Kachadoorian and Péwé (1954) and Kachadoorian (1974) indicate that the till and similar deposits cover much of the area mapped as *ag* These deposits are interspersed with mainly glaciolacustrine and glaciofluvial deposits They may be found in end, lateral and ground moraines with smooth to rough and rolling to locally steep surfaces

Map units fl_1 *and* fl_2

Both map units incorporate areas of complex geology Glacial and fluvial deposits with superimposed lacustrine and sometimes eolian deposits cover most areas (Fig. 24). The topography varies. These areas may be relatively flat planar surfaces with minor depressions, hummocky areas with drained and undrained depressions, well-defined sinuous and linear ridges separated by swales and undrained depressions, or discontinuous terraces near abandoned stream channels. Relief in each case is relatively low, with the well-defined ridges showing maximum relief of about 30 to 40 m. The regional setting of the field sites is mainly broad valleys that were recently glaciated and now contain active streams

The types of sediments observed in the field include till and sediments of similar texture in the ground, end and lateral moraines; glaciolacustrine deposits in old lake plains and deposits beneath active lakes and swamps; fluvial deposits in kames, eskers, outwash plains, terraces and old channels with bars visible on their surfaces; and complex mixtures of each of these (Fig 24). In some cases, well-developed, classical glacial landforms do not contain sediments normally found within them. Also, other ridges and mounds that appear similar in form may, in one instance, contain several deposits of different origins dispersed throughout the same mound or ridge, and in others contain a single material derived from one process. Large areas with numerous lakes may be underlain mainly by deposits of outwash streams, or by till and materials of similar texture (e.g. Fig. 11 near 3 and 4) The lakes, swamps and undrained depressions result predominantly from stagnation, burial and melting of glacier ice Similar observations of the geology were made by Kachadoorian et al (1954) The distinctions between these different deposits were not delineated by the Landsat mapping

Map unit um

This unit, located at the margins of the larger glaciers in the basin, consists of superglacial debris on stagnant or active glacial ice The distribution of the debris appears accurately mapped, but the unit name, "moraine," is misleading, as it describes a landform, rather than general debris or glacier ice

Discussion

Imagery interpretation

The unconsolidated deposits in the Upper Susitna River Basin are clearly more complex

Figure 24. Aerial photograph showing region near Denali Highway (1) and Clearwater Creek (2) The surficial materials at location 3 in map unit ag *consist of till overlain by a thin cover of loess with minor amounts of glaciofluvial and fluvial gravels and sands At location 4 in map unit* ag *materials are also mainly till interspersed with sands and gravels. At locations 5, 6 and 7 mapped as unit* fl_1 *deposits are complex, varying from largely till with a thin loess blanket (6), glaciofluvial sands and gravels in old stream channels and eskers interspersed with till (5), and till and glaciofluvial sands and gravels in morainal ridges with swales and kettles (7) Surficial deposits at location 8 in map unit* fL_2 *are similarly complex materials in kames, eskers and end and ground moraines. Location 9 in map unit* fl_2 *consists of mostly till deposited as lateral and ground moraines Loess may thinly cover some till and glaciofluvial deposits throughout the region. Some geomorphic features evident on the photo include arcuate end and lateral moraines near and below (5), abandoned stream channels below (4) and near (3), and esker below (3) upon which the Denali Highway is located, and the old river channel occupied by an undersized stream (Little Clearwater Creek, 10) Photo taken on 29 July 1977 during NASA mission 364, scale 1:160,000*

than those described by the mapping units of the Landsat-derived map. In part, this was expected; however, because till and materials with similar properties were not recognizable on Landsat imagery, the imagery may be inappropriate for mapping complex glacial deposits in this or similar regions.

Recent studies at active glacier margins (e.g. Boulton 1967, 1968, 1970; Lawson 1979) indicate that the sedimentation processes in this environment are very complex. Studies of Quaternary deposits (e.g. Flint 1971) have also shown regional complexities and interactions of the sedimentary processes and deposits of glacial and related peripheral sedimentary environments (e.g. fluvial, lacustrine). Knowledge of the processes and deposits of glacial environments may, be needed to logically interpret these regions at the scale of Landsat imagery.

Also, the deposits that were clearly misinterpreted were generally located in terrain with a maximum relief of 30 to 60 m. Relief of this magnitude could not be differentiated on Landsat images, and this lack of resolution may account for the inability to distinguish between hummocky moraines, pitted outwash plains and flat ground moraine. Better stereo coverage may help solve this problem.

The Landsat images in areas mapped by Kachadoorian et al. (1954) and in areas where field sites were located did not show distinct color or textural variations that could be related directly to changes in the types of surficial materials present. I suggest that this comparison be continued by earth scientists in cooperation with glacial geologists to determine if subtle variations are apparent on Landsat imagery.

Mapping unit nomenclature

The Landsat-derived mapping units probably should not include genetic terms, as do *ag*, fl_1, fl_2 and *um*, but should only be descriptive as with *b* and *bc*. This would eliminate the errors in genetically interpreting the surficial materials The mapping units for unconsolidated deposits should include statements describing the sediment texture and possibly the interrelationships of the various units Any genetic interpretations should be given separately and include reasons for them This approach to descriptive mapping units does not, however, solve the problem of interpreting the glacial history of the deposits

Examples of descriptive map units for the unconsolidated deposits are.

ag	poorly to well-sorted sands and gravels
fl_1, fl_2	undifferentiated deposits of sorted, fine- to medium-grained sands and silts; may be interspersed with map unit *t*.
t	undifferentiated, unsorted or poorly sorted, fine- to coarse-grained sediments; may be interspersed with sorted deposits of silt, sand or gravel.
tc	undifferentiated complex of unsorted to well-sorted fine- to coarse -grained sediments Single deposits are of insufficient dimensions to map separately.
um	unvegetated debris on stagnant or active glacier ice

The map units *t* and *tc* would represent till and mixed deposits of different origins respectively.

Additional data in the legend could include descriptions of the terrain (slope, relief) and landforms of each mapping unit. Genetic interpretations based upon the descriptions of the sediment, terrain and landforms could also be discussed in the legend, but their inclusion as part of any text accompanying the map would be preferred.

SECTION C. CONCLUSIONS

Daniel E. Lawson and Harlan L. McKim

1. Landsat imagery can be used to map surficial geology on a regional basis in remote areas for preliminary planning purposes. It is a cost-effective way of obtaining general regional information on the location of potential sites for construction materials.

2 Most large areas of exposed bedrock were clearly distinguishable from unconsolidated deposits. As expected, scattered unconsolidated deposits surrounded by bedrock were not recognized by Landsat interpretation.

3. Areas of unconsolidated deposits in which small bedrock outcrops are common were not distinguished from areas without such outcrops Their presence can only be inferred when larger outcrops greater than approximately 58×70 m (the resolution on Landsat imagery) are mixed and scattered among smaller ones

4. Field investigation showed that the types and origins of unconsolidated materials deposited in the glacial and periglacial environment could not be clearly defined with the Landsat imagery This was particularly true for areas of

till and other sediments of similar texture and sorting which were mapped mainly as water-laid sediments.

This inability to differentiate these unconsolidated deposits may result from:

a. Indistinct differences in the Landsat image that would show small variations in relief over short distances. For example, hummocky ground moraine may be indistinguishable from a pitted outwash plain.

b. Sedimentation in the glacial environment resulting from a complex interaction of processes. This complexity often produces deposits of many origins that may be associated with one another and with more than one type of landform. For example, end moraines may consist mainly of till or glaciofluvial deposits, or a relatively featureless terrain underlain by till may be interspersed with terrain bearing features indicative of lacustrine and eolian deposits.

c. Incomplete understanding of the past and present sedimentary environments of the region. Satellite and aircraft imagery can be more accurately interpreted when adequate information is available on the types of environments present in the area.

5. Ground truth observation indicated that the mixed genetic mapping units used on the Landsat map for unconsolidated materials should be avoided, because similar materials may result from different processes. Only descriptive terms for the unconsolidated materials should be used. If necessary, these terms could be given with a separate or tentative interpretation of their origins, including the basis for those interpretations Descriptive units avoid the problem of combining sediments of different origins into incorrect and therefore misleading genetic mapping units.

LITERATURE CITED

Anderson, D M , W.K. Crowder, L.W Gatto, R K Haugen, T.L Marlar, H L. McKim and A. Petrone (1973) An ERTS view of Alaska. Regional analysis of earth and water resources based on satellite imagery CRREL Technical Report 241, 50 p. AD76544219

Anderson, D M., H.L. McKim, L W Gatto, R.K. Haugen, W.K. Crowder, C.W Slaughter, and T L Marlar (1975) Arctic and subarctic environmental analyses utilizing ERTS-1 imagery. Final Project Report submitted to NASA, February

Beikman, H.M. (1974) Preliminary geologic map of the southeast quadrant of Alaska U.S. Geological Survey Miscellaneous Field Studies Map MF-612.

Beikman, H.M., C.D Holloway, and E.M. MacKevett, Jr (1977) Generalized geologic map of the eastern part of southern Alaska U.S. Geological Survey Open File Map 77-169-B.

Bilello, M.A (1975) A winter environmental data survey of the drainage basin of the Upper Susitna River, Alaska CRREL Internal Report 442 (unpublished)

Boulton, G.S. (1967) The development of a complex supraglacial moraine at the margin of Sorbreen, NY Friesland, Vestspitsbergen. *Journal of Glaciology*, vol. 6, p 717-735.

Boulton, G S (1968) Flow tills and related deposits on some Vestspitsbergen glaciers. *Journal of Glaciology*, vol. 7, p 391-412

Boulton, G S (1970) On the origin and transport of glacial debris in Svalbard glaciers. *Journal of Glaciology*, vol 9, p. 231-245

Capps, S.R (1940) Geology of the Alaska railroad region U S Geological Survey Bulletin 907

Cooper, S , P Bock, J. Horowitz and D Foran (1975) The use of ERTS imagery in reservoir management and operation. New England Division, Corps of Engineers

Csejtey, B , Jr (1974) Reconnaissance geologic investigation in the Talkeetna Mountains, Alaska, U S. Geological Survey Open-File Report 74-147

Csejtey, B , Jr , W H Nelson, D L Jones, N.J Silberling, R M Dean, M S Morris, M A. Lanphere, J G Smith and M L Silberman (1978) Reconnaissance geologic map and geochronology, Talkeetna Mountains quadrangle, northern part of Anchorage quadrangle, and southwest corner of Healy quadrangle, Alaska U S Geological Survey Open-File Report 78-558 A

Dean, K G (1979) A geologic evaluation of Landsat satellite imagery in interior Alaska) M S thesis, University of Alaska, Fairbanks, Alaska (unpublished)

Eppley, R A (1965) Earthquake history of the United States Part 1 Stronger earthquakes of the United States Revised edition (through 1963) U S Department of Commerce, Environmental Science Service Administration, Coast and Geodetic Survey, Washington, D C , Report 41-1

Flint, R E (1971) *Glacial and Quaternary Geology* New York John Wiley and Sons

Forbes, R B , T E Smith, and T L Turner (1974) Comparative petrology and structure of the Maclaren, Ruby Range and Coast Range Belts implications for offset along the Denali Fault System (abs) Geological Society of America, Cordilleran Section, p 177

Gary, M., R McAfee, Jr., and C.L Wolf (Eds.) (1972) *Glossary of Geology*. American Geological Institute, Washington, D C

Gatto, L W (1976) Baseline data on the oceanography of Cook Inlet, Alaska. CRREL Report 76-25. AD029358

Gedney, L. and L. Shapiro (1975) Structural lineaments, seismicity and geology of the Talkeetna Mountains Area, Alaska. U.S. Army Corps of Engineers, Alaska District, Anchorage, Alaska

Gilluly, J , A C. Waters, and A.O. Woodford (1968) *Principles of Geology*. San Francisco: W H. Freeman and Company.

Graybeal, G.E., F G Hall, B.H Moore, and E H. Schlosser (1974) ERTS-1 data in support of the National Program of Inspection of Dams. NASA SP-351, p. 1023-1039.

Haugen, R.K., R L. Tuinstra, and C W. Slaughter (1979) A Landsat data collection platform at Devil Canyon site, Upper Susitna Basin, Alaska CRREL Special Report 79-2. AD A068508.

Isacks, B., J. Oliver and L R. Sykes (1968) Seismology and the new global tectonics. *Journal of Geophysical Research*, vol. 73, p. 5855-5899

Kachadoorian, R. (1974) Geology of the Devil Canyon dam site, Alaska U.S. Geological Survey Open-File Report 74-40

Kachadoorian, R , D M. Hopkins and D.R. Nichols (1954) A preliminary report of geologic factors affecting highway construction in the area between the Susitna and Maclaren Rivers, Alaska. U.S. Geological Survey Open File Report.

Kachadoorian, R and T.L. Péwé (1955) Engineering geology of the southern half of the Mt. Hayes A-5 Quadrangle, Alaska. U S Geological Survey Open File Report

Lahr, J C and R Kachadoorian (Undated) Preliminary geologic and seismic evaluation of the proposed Devil Canyon and Watana reservoir areas, Susitna River, Alaska Preliminary U S Geological Survey Report

Lawson, D E (1979) Sedimentological analysis of the western terminus region of the Matanuska Glacier, Alaska. CRREL Report 79-9. AD A072000.

McKenzie, D P and R L Parker (1967) The North Pacific An example of tectonics on a sphere *Nature*, vol 216, p 1276-1280

McKim, H L , T L Marlar and D.M Anderson (1972) The use of ERTS-1 imagery in the National Program for the Inspection of Dams CRREL Special Report 183 AD 754579

McKim, H L and C J Merry (1975) Use of remote sensing to quantify construction material and to define geologic lineations, Dickey-Lincoln School Lakes Project, Maine CRREL Special Report 242 AD A023276

McKim, H L , L W Gatto, C J Merry, D H Anderson and T L Marlar (1975) Land use/vegetation mapping in reservoir management, Merrimack River Basin. CRREL Special Report 233 AD 013490

McKim, H L , L W Gatto, C J Merry B E Brockett, M A Bilello, J E Hobbie, and J Brown (1976a) Environmental analyses in the Kootenai River region, Montana CRREL Special Report 76-13 AD A033500

McKim, H L , L W Gatto, C J Merry, and R K Haugen (1976b) Skylab imagery Application to reservoir management in New England CRREL Special Report 76-7 AD 030329

Moffit, F H. (1912) Headwater Regions of Gulkana and Susitna Rivers, Alaska. U S. Geological Survey Bulletin 498

National Aeronautics and Space Administration (1972) NASA Earth Resources Technology Satellite: ERTS-1 Data Users' Handbook. Goddard Space Flight Center, Document No 715D4249

O'Leary, D W., J D. Friedman, and H A. Pohn (1976) Lineament, linear, lineation Some proposed new standards for old terms. *Geological Society of America Bulletin*, vol. 87, p. 1463-1469.

Plafker, G. (1969) Tectonics of the March 27, 1964 Alaska Earthquake U S. Geological Survey Professional Paper 543-I.

Richter, D.H and N.A Matson, Jr (1971) Quaternary faulting in the eastern Alaska Range. *Geological Society of America Bulletin*, vol, 82, p 1529-1540

Richter, D H and D.L Jones (1973) The structure . . ati-graphy of eastern Alaska Range, Alaska. Amer. .. Association Petroleum Geologists Memoir 19, p 408-420 Also in *Second International Arctic Symposium Proceedings, American Association of Petroleum Geologists Bulletin*

Rieger, S., D.B Schoephorster and C E Furbush (1979) Exploratory soil survey of Alaska U S. Department of Agriculture, Soil Conservation Service

Ruhe, R V. (1975) *Geomorphology, geomorphic processes and surficial geology*. Boston, Mass · Houghton Mifflin Co

Sellmann, P.V., J Brown, R.I Lewellen, H McKim and C Merry (1975) The classification and geomorphic implications of thaw lakes on the Arctic Coastal Plain, Alaska CRREL Research Report 344. AD 021266

Smith, T.E and D.L Turner (1974) Maclaren metamorphic belt of central Alaska (abstract). Geological Society of America, Cordilleran Section, p 257

Thornbury, W D. (1954) *Principles of geomorphology*. New York: John Wiley and Sons, Inc.

Tobin, D.G. and L.R. Sykes (1968) Seismicity and tectonics of the Northeast Pacific Ocean, *Journal of Geophysical Research*, vol. 73, p 3821-3845.

Turner, D L, T E Smith, and R.B Forbes (1974) Geochronology of offset along the Denali Fault System in Alaska (abstract) Geological Society of America, Cordilleran Section, p. 268

U.S Army Corps of Engineers, Alaska District (1978a) Plan of study for Susitna hydropower feasibility analysis. State of Alaska June

U.S. Army Corps of Engineers, Alaska District (1978b) Susitna hydropower feasibility analysis Draft Environmental Assessment, Anchorage, Alaska, December

VanWormer, J.D, J Davies, and L. Gedney (1974) Seismicity and plate tectonics in south-central Alaska. *Bulletin of the Seismological Society of America*, vol. 64, p. 1467-1475.

Waller, L R. (1977) The Denali ASVT remote sensing project, application in Alaska In *Proceedings of a Symposium on North American Forest Lands at Latitudes North of 60 degrees*. University of Alaska, Fairbanks, Alaska, 19-22 September, p 85-107

Wobber, F V and K R. Martin (1973) Exploitation of ERTS-1 imagery utilizing snow enhancement techniques (abstract). Symposium of Significant Results ERTS-1, 5-9 March

GLOSSARY*

Term	*Definition*
Alluvial	Pertaining to or composed of alluvium, or deposited by a stream or running water.
Back Slope	The slope at the back of a scarp; e.g. the gentler slope of a cuesta or of a fault block.
Benioff Seismic Zone	A plane beneath the trenches of the circumPacific belt, dipping towards the continents at an angle of about 45°, along which earthquake foci cluster. It is sometimes referred to as the Benioff fault plane. According to the theory of plate tectonics and sea-floor spreading, plates of the lithosphere sink into the upper mantle through this zone
Colluvium	A general term applied to any loose, heterogeneous, and incoherent mass of soil material or rock fragments deposited chiefly by mass-wasting, usually at the base of a steep slope or cliff, e.g talus, cliff debris, and avalanche material.
Dendritic Drainage Pattern	A drainage pattern in which the streams branch irregularly in all directions and at almost any angle, resembling in plan the branching habit of certain trees, and produced where a consequent stream receives several tributaries which in turn are fed by small tributaries.
Earthquake Magnitude	A measure of the ground motion at a fixed distance from the epicenter and is stated in terms of the Gutenberg-Richter scale. Magnitude is believed to be related to the energy released by the earthquake and is determined from one or more instrument records. The magnitude scale is exponential in character so that an increase of one unit in magnitude signifies a ten-fold increase in ground motion, or roughly a 63-fold increase in energy release. The zero of the scale represents the smallest recorded earthquakes The largest known earthquake magnitudes are about 8 75 (Eppley 1965)
Eolian	Pertaining to the wind.
Epicenter	That point on the Earth's surface which is directly above the focus of an earthquake.
Fault	A surface or zone of rock fracture along which there has been displacement, from a few centimeters to a few kilometers in scale
Fault Zone	A fault that is expressed as a zone of numerous small fractures or of breccia or fault gouge A fault zone may be as wide as hundreds of meters.
Fluvial	Of or pertaining to a river or rivers
Foot Slope	A general term for a hillside surface whose top part is the wash slope and that includes all the slopes of diminishing gradient.

*From Gary et al (1972) unless otherwise indicated

Glaciofluvial	Pertaining to the meltwater streams flowing from wasting glacier ice and especially to the deposits and landforms produced by such streams, as kame terraces and outwash plains.
Graben	An elongate, relatively depressed crustal unit or block that is bounded by faults on its long sides. It is a structural form that may or may not be geomorphologically expressed as a rift valley.
Hypocenter	The focus of an earthquake.
Lacustrine	Pertaining to, produced by, or formed in a lake or lakes.
Lineament	A mappable, simple or composite linear feature of a surface, whose parts are aligned in a rectilinear or slightly curvilinear relationship and which differs distinctly from the patterns of adjacent features and presumably reflects a subsurface phenomenon. Their meaning has been much debated; some certainly express valid structural features, such as faults, aligned volcanoes, and zones of intense jointing with little displacement, but the meaning of others is obscure, and their origins may be diverse, or purely accidental. Also, the term is widely applied to lines representing beds, lithologic horizons, mineral bandings, veins, faults, joints, unconformities, and rock boundaries (O'Leary et al. 1976)
Modified Mercalli Scale	One of the earthquake intensity scales, having 12 divisions ranging from I (not felt by people) to XII (damage nearly total). It is a revision of the Mercalli scale made by Wood and Neumann in 1931. Abbrev: MM scale.
Moraine	A mound, ridge, or other distinct accumulation of unsorted, unstratified glacial drift, predominantly till, deposited chiefly by direct action of glacier ice in a variety of topographic landforms that are independent of control by the surface on which the drift lies.
Outwash	Stratified detritus (chiefly sand and gravel) removed or "washed out" from a glacier by meltwater streams and deposited in front of or beyond the terminal moraine or the margin of an active glacier.
Richter Scale	The range of numerical values of earthquake magnitude, devised in 1935 by the seismologist C.F. Richter. Very small earthquakes, or microearthquakes, can have negative magnitude values. In theory there is no upper limit to the magnitude of an earthquake. However, the strength of Earth materials produces an actual upper limit of slightly less than 9.
Right Lateral Fault	A fault, the displacement of which is right-lateral separation Movement of a lateral fault along which, in plain view, the side opposite the observer appears to have moved to the right.
Scissor Fault	A fault on which there is increasing offset or separation along the strike from an initial point of no offset, with reverse offset in the opposite direction The separation is

commonly attributed to a scissorlike or pivotal movement on the fault, whereas it is actually the result of uniform strike-slip movement along a fault across a synclinal or anticlinal fold.

Strike-Slip Fault	A fault, the actual movement of which is parallel to the strike of the fault.
Subduction Zone	An elongate region along which a crustal block descends relative to another crustal block, e.g. the descent of the Pacific plate beneath the Andean plate along the Andean trench.
Superposed	Shortened form of superimposed. Superimposed means a stream or drainage system let down from above by erosion through the formations on which it was developed onto rocks of different structure lying unconformably beneath.
Talus	Rock fragments of any size or shape (usually coarse and angular) derived from and lying at the base of a cliff or very steep, rocky slope
Thrust Fault	A fault with a dip of 45° or less in which the hanging wall appears to have moved upward relative to the footwall. Horizontal compression rather than vertical displacement is its characteristic feature.
Till	Generally unconsolidated and unstratified sediments, deposited directly by a glacier without subsequent reworking and resedimentation by other processes of the glacial environment. It often consists of a heterogeneous mixture of clay, sand, gravel, and boulders varying widely in size and shape (based on Lawson 1979).

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Bibliography: p. 36.
1. Aerial photography. 2. Environmental surveys. 3. Mapping. 4. Satellites (artificial). 1. C.J. Merry, co-author. II. H.L. McKim, co-author. III. D.E. Lawson, co-author. IV. United States. Army Corps of Engineers. V. Army Cold Regions Research and Engineering Laboratory, Hanover, N.H. VI. Series: CRREL Report 80-4.